# Load Power Factor Study

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# Chapter 1

# Introduction and Study Description

## 1.1 Introduction

Utilities make some customer types, mainly business customers pay a power factor surcharge on their bill if their power factor is below 90%. This is because the meter installed at the large load facility reads kWh, and when the power factor is below 100% at a large customers facility, it is drawing both reactive power and real power. However, the energy charges (cents per KWh) applied to customers accounts only reflects the cost of providing the customer with real power they have consumed.

### 1.1.1 Power Factor

Power factor refers to the ability of an electrical system to convert electric current into useful work such as heat, light, and mechanical motion. To use electrical power efficiently the customer system should draw mostly real power, measured in kilowatts (kW), from the utility system. If the equipment at customer side draws too much reactive power, measured in kilovolt-amperes-reactive (kVAR), it can't perform work as efficiently and limits the capacity of supply utility lines to deliver real power and quality voltage to customer facility.

| POWER FACTOR | POWER FACTOR ALLOWANCE | SURCHARGE |
|---|---|---|
| 100% | but 90% or more | None |
| 90% | but 88% or more | 2% |
| 88% | but 85% or more | 4% |
| 85% | but 80% or more | 9% |
| 80% | but 75% or more | 16% |
| 75% | but 70% or more | 24% |
| 70% | but 65% or more | 34% |
| 65% | but 60% or more | 44% |
| 60% | but 55% or more | 57% |
| 55% | but 50% or more | 72% |
| 50% | | 80% |

Figure 1.1: BC Hydro Power Factor Surcharge

The total power a facility draws, also called apparent power, is the square root of the sum of the squares of real and reactive powers. The ratio of real power to total power is called power factor, and the facilities equipment is performing best when that ratio is between 90% and 100%. The power factor is calculated using the following formula:

$$PowerFactor = \frac{Real\ power\ consumption\ (kWh)}{Apparent\ power\ consumption\ (\sqrt{kWh^2 + kVARh^2})}$$

With BC Hydro, the power factor surcharge applied to the customer's account when the customers power factor is below 90% is as shown in Figure 1.1. The surcharge is used to recover the cost of supplying reactive power to the customer, which isnt included in other charges.

As poor power factors can cause voltage fluctuations and power quality issues and limits the capacity of utility lines to deliver energy to customers. To counteract these effects utilities need to install capacitors on the system to use the utility lines more efficiently and to maintain power quality.

## 1.2 Study Description

In the present study, PV analysis is carried out on the hypothetical SAVNW study system in PSSE for various load power factors for connected load at bus 205 with an initial MW requirement of 20 MW to determine the maximum power that can be transmitted from the sources in Area 2 (generator at bus 211 and bus 206) to the connected load at sink bus 205 for the following 2 study cases.

- When load bus 205 is not connected with any shunt capacitor
- When load bus 205 is connected with shunt capacitor of 300 MVAR as in the original hypothetical SAVNW study system

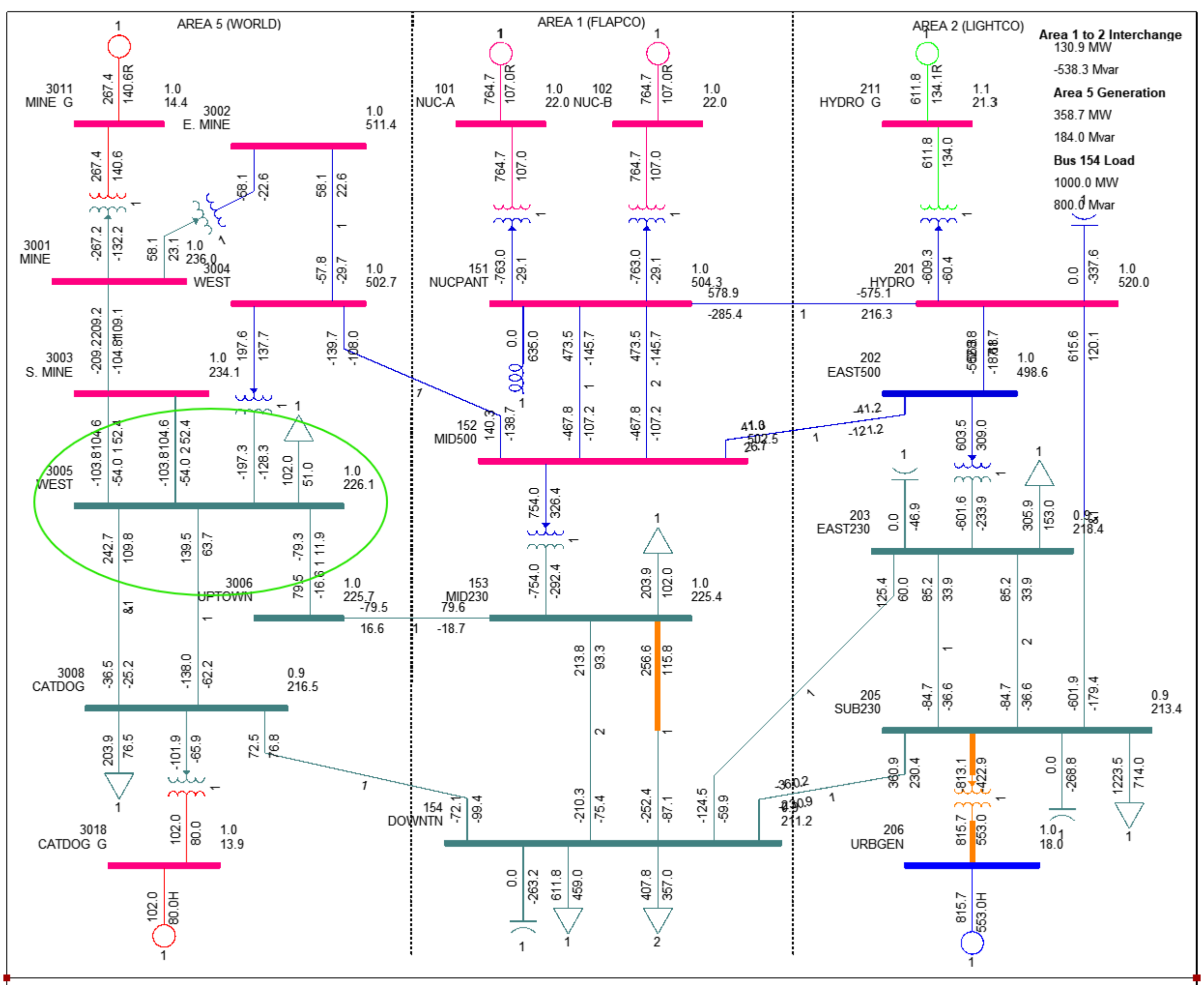


Figure 1.2: Hypothetical SAVNW study system considered for the study

Chapter 2 gives the study results for maximum incremental power transfer and desired incremental transfer for various power factors ranging from 0.45 to UPF in increments of 0.05. Corresponding to these transfers bus voltage at load bus, generator MW and MVAR values, load MW and MVAR values, and branch MVA flows are extracted from PSSE PV analysis excel file.

Chapter 3 Evaluates the observed study results

Appendix 4 gives the PSSE automation Python script used to obatin the PV analysis result in excel format and functions developed to extract the observed Bus voltages, Bus Load MWs and MVARs, Generator MWs and MVAR Dispatches, and Branch flows from the PV excel file.

# Chapter 2

# PV Study results

## 2.1 Introduction

In this chapter PV analysis results are extracted for maximum incremental transfer and desired incremental transfer for each power factor for the 2 study cases. For the studied cases results extracted are Voltages at bus 205, Real power consumption of connected load at bus 205, Reactive power consumption of connected load at bus 205, Real power generation at bus 211 HYDRO_G, Reactive power generation at bus 211 HYDRO_G, Reactive power generation at bus 206 URBGEN, and Real power generation at bus 206 URBGEN. In this chapter, Section 2.2 gives the extracted results for the 2 studied cases for maximum incremental transfer and Section 2.3 gives the extracted results for the 2 studied cases for desired incremental transfer. Following are the considerations taken into account for analysing the extracted results:

- The normal operating range of voltage for the studied hypothetical system is 0.95 PU - 1.05 PU.
- The emergency operating range of voltage for the studied hypothetical system is 0.9 PU - 1.1 PU.
- The Generation in area 2 is serving the connected loads at bus 203, 205, +/- inter area transfers to area 1, and the losses.
- Economic dispatch is considered for this study, the generator at bus 211 is committed first and then only the generator at Bus 206 committed for generation based on the load requirement.
- For most duration of operation for lower power factors, the machine at 206 operates as a motor serving the required reactive power.

## 2.2 Maximum Incremental Transfer

For each power factor studied, Maximum Incremental Transfer, Voltages at bus 205, Real power consumption of connected load at bus 205, Reactive power consumption of connected load at bus 205, Real power generation at bus 211 HYDRO_G, Reactive power generation at bus 211 HYDRO_G, Reactive power generation at bus 206 URBGEN, and Real power generation at bus 206 URBGEN with and without the shunt capacitor connection at Bus 205 is given in Tables 2.1 and 2.2. As can be seen from the Tables, the maximum power that can be transferred for each of the power factors is more when the shunt is connected at Bus 205.

### 2.2.1 Without Shunt Capacitor at Bus 205

When a shunt capacitor is not connected at Bus 205, for the studied power factors, the bus voltage at the connected load Bus 205 is outside the normal low voltage limit of 0.95 for all power factors except PF = 1.0. Taking PF = 0.45 as an example, a maximum incremental transfer of 400 MW is possible when initial connected load has a MW requirement of 20 MW, giving Load P as 420 MW and Load Q as 833.49 MVAR with a Bus Voltage of 0.84 PU. As economic dispatch is considered, the generators at Bus 211 is dispatched first and then the unit at 206, correspondingly for PGen = 616.25 and Qgen = 400 MVAR for 211 HYDRO_G and PGen = 39.85 MW and Qgen = 600 MVAR for 206 URBGEN. As power factor increases, reactive power requirement of load decreases and maximum possible incremental transfer increases. As the unit at 211 is working at its maximum generation capacity, as the power factor increases, and MW requirement increases generator at Bus 206 generates more real power. Maximum power transfer possible for the studied case is 1260 MW for Power Factors equal to 0.88, 0.9 and UPF with corresponding voltages at the load bus of 0.87 PU, 0.9 PU and 0.98 PU. The voltages corresponding to Power factors 0.88 is outside the normal and emergency operating voltage range of the hypothetical SAVNW study system, whereas the voltage corresponding to power factor of 0.9 is outside the normal range but on the edge of emergency range. The machine at Bus 206 serves the reactive power needed for the connected load at 205 by operating at its reactive power limit, the additional reactive power needed is only served by unit connected at 211. This is evident for when load power factor = 1.0, where the Qgen 211 = -100 MVAR and connected load at Bus 203's reactive power demand is met by generator at bus 206.

| **Load PF** | **Bus Voltage** | **Maximum Incremental Transfer** | **Load P** | **Load Q** | **Pgen 206 URBGEN** | **Qgen 206 URBGEN** | **Pgen 211 HYDRO_G** | **Qgen 211 HYDRO_G** |
|---|---|---|---|---|---|---|---|---|
| PF = 0.45 | 0.84 | 400 | 420.0 | 833.49 | 39.85 | 600.0 | 616.25 | 400.0 |
| PF = 0.5 | 0.84 | 460 | 480.0 | 831.36 | 99.93 | 600.0 | 616.25 | 400.0 |
| PF = 0.55 | 0.85 | 520 | 540.0 | 819.72 | 159.15 | 600.0 | 616.25 | 400.0 |
| PF = 0.6 | 0.83 | 600 | 620.0 | 826.46 | 239.77 | 600.0 | 616.25 | 400.0 |
| PF = 0.65 | 0.84 | 680 | 700.0 | 818.3 | 319.11 | 600.0 | 616.25 | 400.0 |
| PF = 0.7 | 0.84 | 770 | 790.0 | 805.8 | 408.92 | 600.0 | 616.25 | 400.0 |
| PF = 0.75 | 0.85 | 870 | 890.0 | 784.53 | 508.95 | 600.0 | 616.25 | 400.0 |
| PF = 0.8 | 0.85 | 1000 | 1020.0 | 765.0 | 639.05 | 600.0 | 616.25 | 400.0 |
| PF = 0.85 | 0.86 | 1150 | 1170.0 | 724.81 | 789.07 | 600.0 | 616.25 | 400.0 |
| PF = 0.88 | 0.87 | 1260 | 1280.0 | 690.56 | 899.08 | 600.0 | 616.25 | 400.0 |
| PF = 0.9 | 0.9 | 1260 | 1280.0 | 619.52 | 898.79 | 600.0 | 616.25 | 289.36 |
| PF = 1.0 | 0.98 | 1260 | 1280.0 | 0.0 | 888.76 | 275.53 | 616.25 | -100.0 |

Table 2.1: PV results summary without any shunt connected at Bus 205

### 2.2.2 With a Shunt Capacitor of 300 MVAR connected at Bus 205

When shunt capacitor of 300 MVAR is connected at Bus 205, for the studied power factors, the bus voltage at the connected load Bus 205 is within the normal low voltage limit of 0.95 for power factors greater than 0.88, an improvement from without the shunt operation. From power factors 0.85 and up maximum incremental transfer of 1260 MW is possible with voltage of operation greater than 0.9 PU. Taking PF = 0.55 as an example, a maximum incremental transfer of 650 MW is possible when initial connected load has a MW requirement of 20 MW, giving Load P as 670 MW and Load Q as 1017.06 MVAR with a Bus Voltage of 0.88 PU. As economic dispatch is considered, the generators at Bus 211 is dispatched first and then the unit at 206, correspondingly for PGen = 616.25 MW and Qgen = 386.56 MVAR for 211 HYDRO_G and PGen = 284.33 MW and Qgen = 600 MVAR for 206 URBGEN.

Unit at Bus 206 is operating at its reactive power limit for the connected loads for power factors 0.9 and less for the studied case. When the shunt is connected at Bus 206 and connected load at bus 206 is operating at UPF, the shunt supplies the reactive power requirement for load at 203 and associated reactive power losses, giving the Qgen at Bus 206 for UPF operation with shunt = 0 MVAR.

## 2.3 Desired Incremental Transfer

In this section a comparison study is carried out for various power factors when the connected load has a MW requirement of 600 MW. Two cases are studied for various power factors as before.

| Load PF | Bus Voltage | Maximum Incremental Transfer | Load Pmax | Load Qmax | Pgen 206 URBGEN | Qgen 206 URBGEN | Pgen 211 HYDRO_G | Qgen 211 HYDRO_G |
|---|---|---|---|---|---|---|---|---|
| PF = 0.45 | 0.88 | 500 | 520.0 | 1031.94 | 137.0 | 600.0 | 616.25 | 396.07 |
| PF = 0.5 | 0.88 | 570 | 590.0 | 1021.88 | 205.51 | 600.0 | 616.25 | 384.25 |
| PF = 0.55 | 0.88 | 650 | 670.0 | 1017.06 | 284.33 | 600.0 | 616.25 | 386.56 |
| PF = 0.6 | 0.88 | 740 | 760.0 | 1013.08 | 378.95 | 600.0 | 616.25 | 396.74 |
| PF = 0.65 | 0.88 | 830 | 850.0 | 993.65 | 468.64 | 600.0 | 616.25 | 381.91 |
| PF = 0.7 | 0.88 | 940 | 960.0 | 979.2 | 576.27 | 600.0 | 616.25 | 382.35 |
| PF = 0.75 | 0.88 | 1070 | 1090.0 | 960.83 | 705.29 | 600.0 | 616.25 | 395.25 |
| PF = 0.8 | 0.88 | 1210 | 1230.0 | 922.5 | 854.95 | 600.0 | 616.25 | 385.54 |
| PF = 0.85 | 0.92 | 1260 | 1280.0 | 792.96 | 893.42 | 600.0 | 616.25 | 171.58 |
| PF = 0.88 | 0.95 | 1260 | 1280.0 | 690.56 | 892.85 | 600.0 | 616.25 | 20.59 |
| PF = 0.9 | 0.97 | 1260 | 1280.0 | 619.52 | 892.45 | 600.0 | 616.25 | -70.6 |
| PF = 1.0 | 0.99 | 1260 | 1280.0 | 0.0 | 889.01 | 0.0 | 616.25 | -100.0 |

Table 2.2: PV results summary with shunt of 300 MVAR connected at Bus 205

### 2.3.1 Without the Shunt at Bus 205

As already seen in Table 2.1, for PF = 0.45 - maximum incremental transfer possible is 400 MW, for PF = 0.5, maximum incremental transfer possible is 460 MW, and for PF = 0.55, maximum incremental transfer possible is 520 MW.

| Load PF | Bus Voltage | Load MW | Load MVAR | Pgen 206 URBGEN | Qgen 206 URBGEN | Pgen 211 HYDRO_G | Qgen 211 HYDRO_G |
|---|---|---|---|---|---|---|---|
| PF = 0.45 | | | | | | | |
| PF = 0.5 | | | | | | | |
| PF = 0.55 | | | | | | | |
| PF = 0.6 | 0.83 | 610.0 | 813.13 | 219.77 | 600.0 | 616.25 | 400.0 |
| PF = 0.65 | 0.9 | 620.0 | 724.78 | 219.11 | 600.0 | 616.25 | 250.18 |
| PF = 0.7 | 0.92 | 620.0 | 632.4 | 218.92 | 600.0 | 616.25 | 131.49 |
| PF = 0.75 | 0.94 | 620.0 | 546.53 | 208.8 | 600.0 | 616.25 | 35.07 |
| PF = 0.8 | 0.96 | 620.0 | 465.0 | 208.79 | 600.0 | 616.25 | -50.63 |
| PF = 0.85 | 0.98 | 620.0 | 384.09 | 208.79 | 579.6 | 616.25 | -100.0 |
| PF = 0.88 | 0.98 | 620.0 | 334.49 | 208.78 | 524.77 | 616.25 | -100.0 |
| PF = 0.9 | 0.98 | 620.0 | 300.08 | 208.78 | 487.11 | 616.25 | -100.0 |
| PF = 1.0 | 0.98 | 620.0 | 0.0 | 208.76 | 171.9 | 616.25 | -100.0 |

Table 2.3: PV results summary without any shunt connected at Bus 205 for a desired transfer of 600 MW

Hence an incremental transfer of 600 MW is not possible for these power factors. For the rest of the studied Power factors, for the same incremental transfer of 600 MW, the Load MVAR requirement decreases as Power factor increases. Except for PF = 0.6, all the observed voltages are within the normal operating range.

### 2.3.2 With the Shunt of 300 MVAR connected at Bus 205

As already observed in Table 2.2, for PF = 0.45, maximum incremental transfer possible is 500 MW and for PF = 0.5, maximum incremental transfer possible is 570 MW. Hence an incremental transfer of 600 MW is not possible for these power factors. For the rest of the studied Power factors, for the same incremental transfer of 600 MW, the Load MVAR requirement decreases as Power factor increases. For rest of the Power factor cases studied, the observed voltages are within the normal operating range.

| Load PF | Bus Voltage | Load MW | Load MVAR | Pgen 206 URBGEN | Qgen 206 URBGEN | Pgen 211 HYDRO_G | Qgen 211 HYDRO_G |
|---|---|---|---|---|---|---|---|
| PF = 0.45 | | | | | | | |
| PF = 0.5 | | | | 205.51 | 600.0 | 616.25 | 384.25 |
| PF = 0.55 | 0.9 | 620.0 | 941.16 | 214.33 | 600.0 | 616.25 | 194.68 |
| PF = 0.6 | 0.94 | 620.0 | 826.46 | 208.14 | 600.0 | 616.25 | 39.65 |
| PF = 0.65 | 0.96 | 620.0 | 724.78 | 217.34 | 600.0 | 616.25 | -86.07 |
| PF = 0.7 | 0.98 | 620.0 | 632.4 | 216.27 | 521.74 | 616.25 | -100.0 |
| PF = 0.75 | 0.98 | 620.0 | 546.53 | 215.29 | 428.76 | 616.25 | -100.0 |
| PF = 0.8 | 0.98 | 620.0 | 465.0 | 214.34 | 342.25 | 616.25 | -100.0 |
| PF = 0.85 | 0.98 | 620.0 | 384.09 | 213.42 | 258.09 | 616.25 | -100.0 |
| PF = 0.88 | 0.98 | 620.0 | 334.49 | 212.85 | 207.34 | 616.25 | -100.0 |
| PF = 0.9 | 0.98 | 620.0 | 300.08 | 212.45 | 172.5 | 616.25 | -100.0 |
| PF = 1.0 | 1.04 | 620.0 | 0.0 | 209.01 | 0.0 | 616.25 | -100.0 |

Table 2.4: PV results summary with shunt of 300 MVAR connected at Bus 205 for a desired transfer of 600 MW

## 2.4 Observations

In this chapter the results of PV analysis conducted is studied to see the variation in studied parametes as power factor increases from 0.45 to 1 at an incremental rate of 0.05.

# Chapter 3

# Study Result Analysis

## 3.1 Introduction

In this chapter results obtained are plotted to compare various parameters studied for power transfer from source buses to sink bus for the 2 studied cases of when bus 205 in Area 1 is connected with and without shunt.

## 3.2 Maximum Power Transfer Capability

When shunt is connected at bus 205 it can be seen that the maximum power transfer capabilty is higher, as the connected shunt not only improves the voltage at the bus, but also supplies reactive power to the connected load allowing more MW transfer.

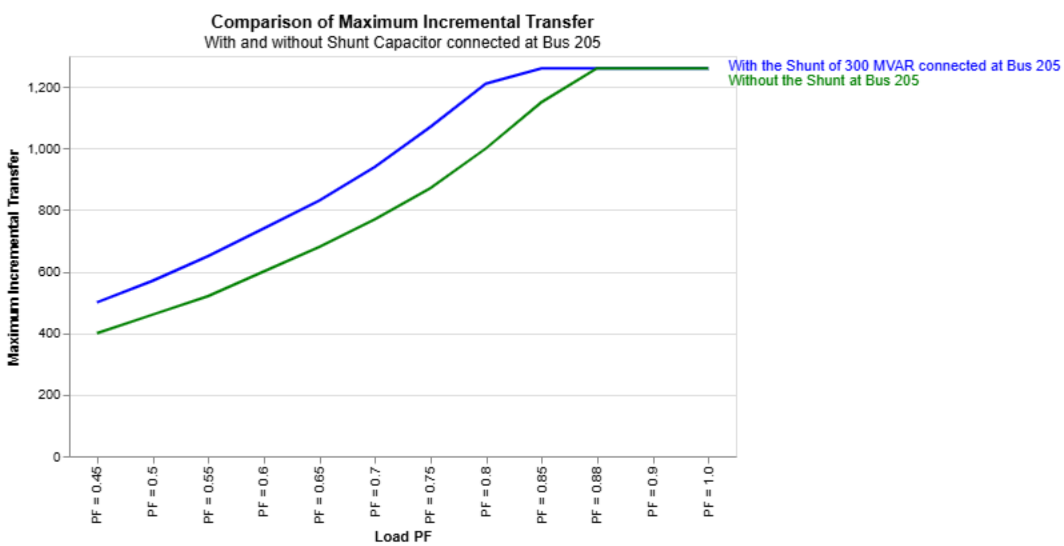


Figure 3.1: Maximum Incremental Power Transfered

## 3.3 Branch Flow

When the customer load is operating at a low power factor, It limits the capacity of utility lines to deliver energy to the connected load and to connected loads at other buses. This was studied by comparing branch flows for various branches. For 2 of the studied branch flows 201 HYDRO - 202 EAST500 and 201 HYDRO - 204 SUB500, it can be seen in Figure 3.3 that for the same incremental transfer of 600 MW, less line capacity is needed when shunt of 300 MVAR is connected at Bus 205. The detailed comparison of all the branch flows is available in Branch Flow Analysis

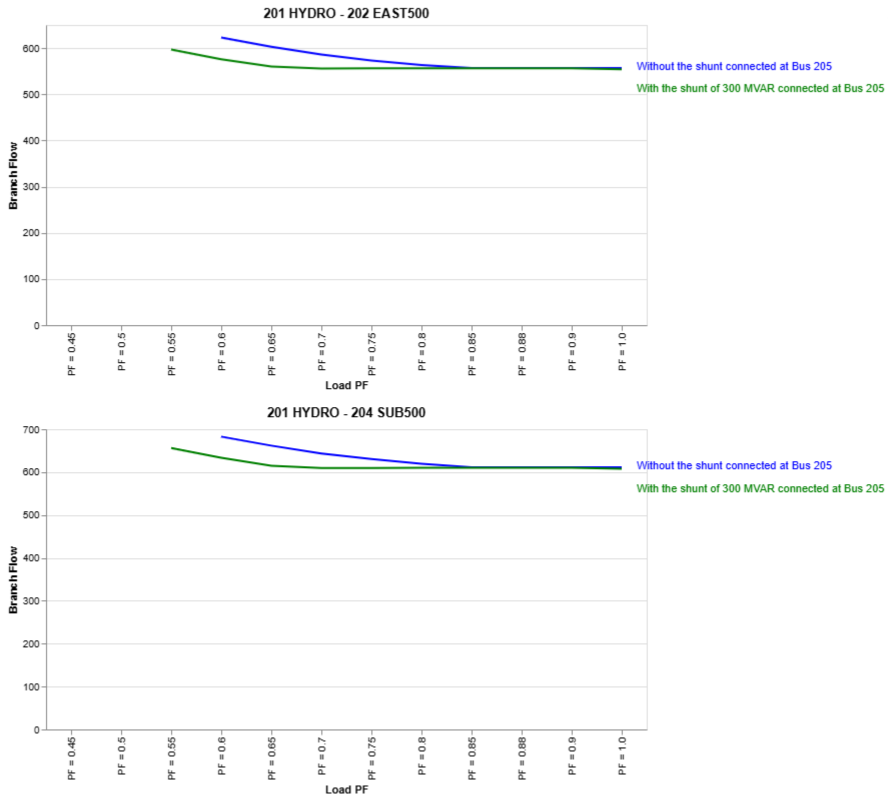


Figure 3.2: Branch Flows

## 3.4 Bus Voltage

The voltage is higher with the Shunt Capacitor connected at the load bus 205, not only it improves the voltage at the connected load bus, but also improves the voltage at other buses as well. The comparison of rest of the bus voltages is available in Bus Voltage Analysis

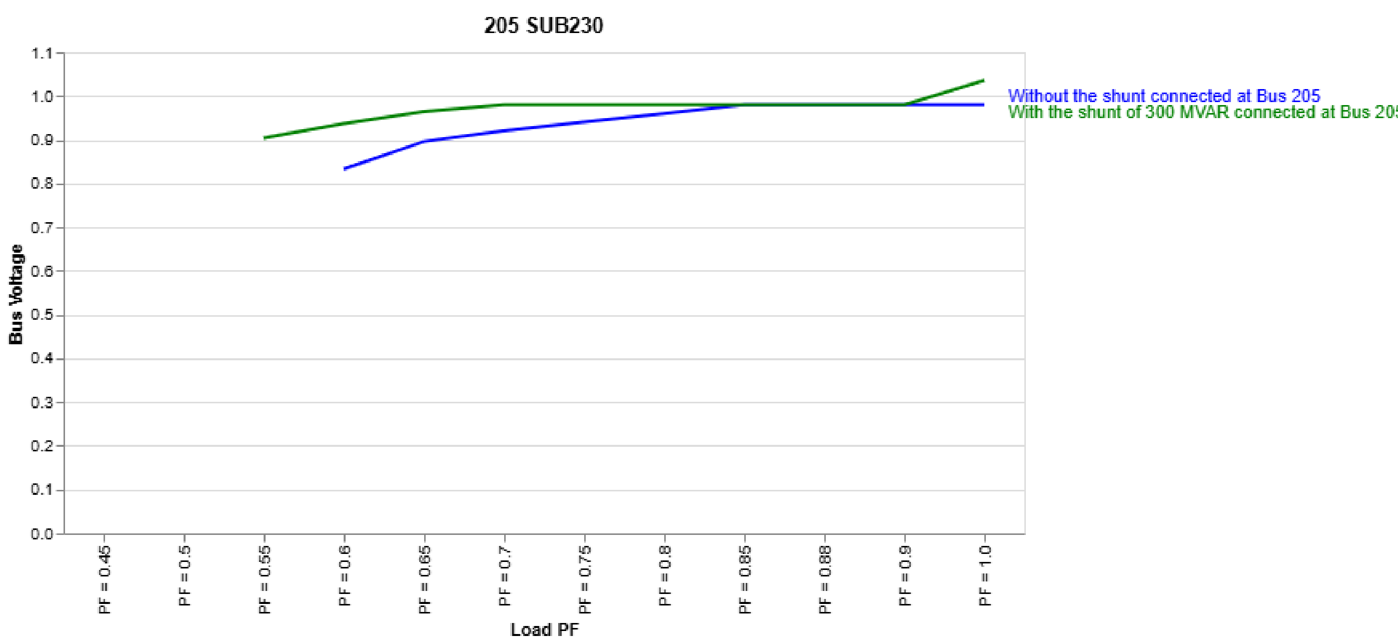


Figure 3.3: Bus Voltage at bus 205

## 3.5 Load Power Consumption

As can be seen from the table for the same load requirement of 620 MW, as power factor increases the load MVAR requirement and corresponding Load MVA value decreases. When the power factor is below 100%, it can be seen that in addition to the real power load also draws reactive power resulting in higher apparent power for lower PF. Hence a power factor surcharge is applied to the account when the power factor is below 90%. It is used to recover the cost of supplying reactive power to the customer, which isnt included in other charges.

| Load PF | Load MW | Load MVAR | Load MVA |
|---|---|---|---|
| PF = 0.55 | 620.0 | 941.16 | 1127.02 |
| PF = 0.6 | 620.0 | 826.46 | 1033.17 |
| PF = 0.65 | 620.0 | 724.78 | 953.79 |
| PF = 0.7 | 620.0 | 632.4 | 885.62 |
| PF = 0.75 | 620.0 | 546.53 | 826.5 |
| PF = 0.8 | 620.0 | 465.0 | 775.0 |
| PF = 0.85 | 620.0 | 384.09 | 729.33 |
| PF = 0.88 | 620.0 | 334.49 | 704.47 |
| PF = 0.9 | 620.0 | 300.08 | 688.8 |
| PF = 1.0 | 620.0 | 0.0 | 620.0 |

Table 3.1: Load MVAR and MVA variation for the same Load MW with different Power Factors

# Chapter 4

# Conclusions

In this study, analysis is carried out to determine the effect of load power factor on maximum incremental transfer possible from source buses to the sink bus at 205 when a shunt is connected and not connected at the bus. Results were also observed for variation of line capacity and voltage with and without the shunt capacitor for the desired incremental transfer of 600 MW. It was seen that when shunt is connected at the load bus:

- maximum power that can be transferred from source to sink increases.
- for the same incremental transfer, less line capacity is needed for power flow
- the voltage at the load bus was higher

It was also observed that as the connected load power factor increases, to serve the same real power load value, the reactive power requirement is less. It can be concluded that by improving the power factor not only the customer can have monetary savings, but it is also better for the utility system in terms of line capacity savings, increased power transfer capability for the system and better voltages at buses

# Appendix

## 4.1 Python script to conduct PV analysis and to obtain results in excel format in PSSE

```
import pssexcel
loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
for load in loads:
    psspy.case(r"""savnw_wo_shunt.sav""") # use file savnw.sav for with shunt study
    file_dfx= 'savnw_' + str(load) + '.dfx'
    file_pv = 'savnw_' + str(load) + '.pv'
    file_name_dfx = r"{}".format(file_dfx)
    file_name_pv = r"{}".format(file_pv)
    psspy.load_chng_6(205,r"""1""",[_i,_i,_i,_i,_i,_i,_i],[_f,load,_f,_f,_f,_f,_f,_f],"")
    psspy.fdns([0,0,0,0,1,1,99,0])
    psspy.dfax_2([1,1,0],r"""savnwSub.sub""",r"""savnwmon.mon""",r"""savnwcon.con""",file_name_dfx
                                                            )
    psspy.pv_engine_6([0,1,0,1,0,0,0,2,0,0,1,1,4,1,0,0,0,0,0,0,0,1,0,0,0,0],[0.5,20.0,10.0,2500.0,0.
                                                            9,100.0,0.0,0.0],[r"""SOURCE""",r"""SINK""",r
                                                            """SOURCE"""],
    file_name_dfx,"",r"""savnw.ecd""","",file_name_pv,"")
    pssexcel.pv(file_name_pv,['v','g','l','b'],colabel=['base case'],xlsfile='book.xlsx',sheet=str
                                                            (load),overwritesheet=True,show=False)
```

## 4.2 Python function to extract Generator MW and MVAR for maximum possible incremental transfer

```
def function_gen(book_name):
"""
input:
  book_name: PV result obtained in excel format
output:
  dataframe: the extracted result
"""
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    gen_sheets = []
    for gen in loads:
        sheet = str(gen) + ' Generator Dispatch'
        gen_sheets.append(sheet)
    gen_df_list = []
    for gen_sheet in gen_sheets:
        data = pd.read_excel(book_name,sheet_name = gen_sheet, header=2)
        data[['Unnamed: 0', 'Unnamed: 1']] = data[['Unnamed: 0', 'Unnamed: 1']].astype(str)
        data_bus = data.iloc[:,:2]
        data['Generator Bus Name'] = data_bus[['Unnamed: 0', 'Unnamed: 1']].agg(' '.join, axis=1)
        data_power = data.iloc[:,-3:]
        data_power = data_power.rename(columns={data_power.columns[0]: "Generator MW", data_power.
                                                            columns[1]: "Generator MVAR"})
        data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(gen_sheet.split(' ')
                                                            [0])/20))),2))
        gen_df_list.append(data_power)
    df_gen = pd.concat(gen_df_list).reset_index(drop=True)
    return df_gen
```

## 4.3 Python Function to extract generator MW and MVAR for desired incremental transfer

```
def function_gen_desired(book_name, desired_power):
"""
input:
  book_name: PV result obtained in excel format
  desired_power: The value of desired incremental transfer for which the generator MW and MVAR is
                                                  extracted
output:
  dataframe: the extracted result
"""
    import numpy as np
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    load_sheets =  []
    df_gen_list = []
    for load in loads:
        sheet_name = str(load) + ' Generator Dispatch'
        load_sheets.append(sheet_name)
    for load_sheet in load_sheets:
        data = pd.read_excel(book_name ,sheet_name = load_sheet, header=2)
        data[['Unnamed: 0', 'Unnamed: 1']] = data[['Unnamed: 0', 'Unnamed: 1']].astype(str)
        data_bus = data.iloc[:,:2]
        data['Generator Bus Name'] = data_bus[['Unnamed: 0', 'Unnamed: 1']].agg(' '.join, axis=1)
        data_power = data
        n = str(int(desired_power/20))
        mw_name = 'MW.' + n
        mvar_name ='MVAR.' +n
        if mw_name in data_power:
            data_power = data[['Generator Bus Name',mw_name, mvar_name]]
        else:
            data_power[mw_name] = np.nan
            data_power[mvar_name] = np.nan
            data_power = data[['Generator Bus Name',mw_name, mvar_name]]
        data_power = data_power.rename(columns={data_power.columns[1]: "Generator MW", data_power.
                                                 columns[2]: "Generator MVAR"})
        data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(load_sheet.split(' '
                                                 )[0])/20))),2))
        df_gen_list.append(data_power)
    df_gen = pd.concat(df_gen_list).reset_index(drop=True)
    return df_gen
```

## 4.4 Python function to extract load MW and MVAR for maximum possible incremental transfer

```
def function_load(book_name):
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    load_sheets =  []
    df_load_list = []
    for load in loads:
        sheet_name = str(load) + ' Bus Load'
        load_sheets.append(sheet_name)
    for load_sheet in load_sheets:
        data = pd.read_excel(book_name ,sheet_name = load_sheet, header=2)
        data[['Unnamed: 0', 'Unnamed: 1']] = data[['Unnamed: 0', 'Unnamed: 1']].astype(str)
        data_bus = data.iloc[:,:2]
        data['Load Bus Name'] = data_bus[['Unnamed: 0', 'Unnamed: 1']].agg(' '.join, axis=1)
        data_power = data.iloc[:,-3:]
        data_power = data_power.rename(columns={data_power.columns[0]: "Load MW", data_power.
                                                 columns[1]: "Load MVAR"})
        data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(load_sheet.split(' '
                                                 )[0])/20))),2))
        df_load_list.append(data_power)
    df_load = pd.concat(df_load_list).reset_index(drop=True)
    return df_load
```

## 4.5 Python Function to extract load MW and MVAR for desired incremental transfer

```
def function_load_desired(book_name, desired_power):
    import numpy as np
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    load_sheets =  []
    df_load_list = []
    for load in loads:
        sheet_name = str(load) + ' Bus Load'
        load_sheets.append(sheet_name)
    for load_sheet in load_sheets:
        data = pd.read_excel(book_name ,sheet_name = load_sheet, header=2)
        data[['Unnamed: 0', 'Unnamed: 1']] = data[['Unnamed: 0', 'Unnamed: 1']].astype(str)
        data_bus = data.iloc[:,:2]
        data['Load Bus Name'] = data_bus[['Unnamed: 0', 'Unnamed: 1']].agg(' '.join, axis=1)
        data_power = data
        n = str(int(desired_power/20))
        mw_name = 'MW.' + n
        mvar_name ='MVAR.' +n
        if mw_name in data_power:
            data_power = data[['Load Bus Name',mw_name, mvar_name]]
        else:
            data_power[mw_name] = np.nan
            data_power[mvar_name] = np.nan
            data_power = data[['Load Bus Name',mw_name, mvar_name]]
        data_power = data_power.rename(columns={data_power.columns[1]: "Load MW", data_power.
                                            columns[2]: "Load MVAR"})
        data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(load_sheet.split(' '
                                            )[0])/20))),2))
        df_load_list.append(data_power)
    df_load = pd.concat(df_load_list).reset_index(drop=True)
    return df_load
```

## 4.6 Python functions to extract branch flows for maximum possible incremental transfer

```
def function_flow(book_name, sheet):
    """
    inputs: book_name, sheet
            book_name -> the obtained PV Excel file (.xlsx file type)
            sheet -> sheet name in the Excel file ('string')
    output: dataframe -> dataframe correspondin to the load (DataFrame)
    """
    data = pd.read_excel(book_name, sheet_name=sheet, header=1)
    data_bus = data.iloc[:,:6]
    data_bus[[data_bus.columns[0], data_bus.columns[1], data_bus.columns[2],data_bus.columns[3],
                                                 data_bus.columns[4], data_bus.columns[5]]] =
                                                 data_bus[[data_bus.columns[0], data_bus.
                                                 columns[1], data_bus.columns[2], data_bus.
                                                 columns[3], data_bus.columns[4], data_bus.
                                                 columns[5]]].astype(str)
    data_bus['to'] = ' - '
    data['Bus Flow'] = data_bus['MW TRANSFER->']+ ' ' + data_bus['Unnamed: 1'] + data_bus['to']  +
                                                  data_bus['Unnamed: 3'] +  ' ' + data_bus['
                                                 Unnamed: 4']
    data_power = data.iloc[:,-2:]
    data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(volt_sheet.split(' ')[0]
                                                 )/20))),2))
    Max_power = data_power.columns[0]
    data_power['Maximum Incremental Transfer'] = Max_power
    data_power = data_power.rename(columns={data_power.columns[0]: "Branch Flow"})
    return(data_power)
```

```
def function_MIT_all(book_name):
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    volt_sheets = []
    for volt in loads:
        sheet = str(volt) + ' Branch Flow'
        volt_sheets.append(sheet)
    volt_df_list = []
    for volt_sheet in volt_sheets:
        df = function_flow(book_name, volt_sheet) # the book_name used here
        volt_df_list.append(df)
    df_flow = pd.concat(volt_df_list).reset_index(drop=True)
    return(df_flow)
```

## 4.7 Python Functions to extract branch flows for desired incremental transfer

```
def function_flow_desired(book_name, sheet, desired_incremental_transfer):
    import numpy as np
    """
    inputs: book_name, sheet
            book_name -> the obtained PV Excel file (.xlsx file type)
            sheet -> sheet name in the Excel file ('string')
            desired_incremental_transfer -> desired incremental transfer in MW (int)
    output: dataframe -> dataframe corresponind to the load (DataFrame)
    """
    data = pd.read_excel(book_name, sheet_name=sheet, header=1)
    data_bus = data.iloc[:,:6]
    data_bus[[data_bus.columns[0], data_bus.columns[1], data_bus.columns[2],data_bus.columns[3],
                                                 data_bus.columns[4], data_bus.columns[5]]] =
                                                 data_bus[[data_bus.columns[0], data_bus.
                                                 columns[1], data_bus.columns[2], data_bus.
                                                 columns[3], data_bus.columns[4], data_bus.
                                                 columns[5]]].astype(str)
    data_bus['to'] = ' - '
    data['Branch Flow'] = data_bus['MW TRANSFER->']+ ' ' + data_bus['Unnamed: 1'] + data_bus['to']
                                                   + data_bus['Unnamed: 3'] +  ' ' + data_bus[
                                                 'Unnamed: 4']
    data_power = data
    if desired_incremental_transfer in data_power:
        data_power = data[['Branch Flow',desired_incremental_transfer]]
        col = list(data_power.columns)
        desired_incremental_transfer = col[1]
        data_power = data_power[['Branch Flow',desired_incremental_transfer]]
        new_bus_name = 'Branch Flow for incremental transfer of '+ str(
                                                     desired_incremental_transfer) + ' MW'
        data_power = data_power.rename(columns={data_power.columns[1]:new_bus_name})
    else:
        data_power[desired_incremental_transfer] = np.nan
        data_power = data_power[['Branch Flow',desired_incremental_transfer]]
        new_bus_name = 'Branch Flow for incremental transfer of '+ str(
                                                     desired_incremental_transfer) + ' MW'
        data_power = data_power.rename(columns={data_power.columns[1]:new_bus_name})
    return data_power
```

```
def function_flow_all(book_name, desired_flow):
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    volt_sheets = []
    for volt in loads:
        sheet = str(volt) + ' Branch Flow'
        volt_sheets.append(sheet)
    volt_df_list = []
    for volt_sheet in volt_sheets:
        df = function_flow_desired(book_name, volt_sheet, desired_flow)
        df['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(volt_sheet.split(' ')[0])/20
                                                     ))),2))# the book_name used here
        volt_df_list.append(df)
    df_flow= pd.concat(volt_df_list).reset_index(drop=True)
    return df_flow
```

## 4.8 Python Functions to extract bus voltages for maximum incremental transfer

```
def function_volt(book_name, sheet):
    data = pd.read_excel(book_name, sheet_name=sheet, header=1)
    data_bus = data.iloc[:,:2]
    data_bus[[data_bus.columns[0], data_bus.columns[1]]] = data_bus[[data_bus.columns[0],data_bus.
                                                        columns[1]]].astype(str)
    data['Bus Name'] = data_bus[[data_bus.columns[0],data_bus.columns[1]]].agg(' '.join, axis=1)
    data_power = data.iloc[:,-2:]
    data_power['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(volt_sheet.split(' ')[0]
                                                        )/20))),2))
    Max_power = data_power.columns[0]
    data_power['Maximum Incremental Transfer'] = Max_power
    data_power = data_power.rename(columns={data_power.columns[0]: "Bus Voltage"})
    return(data_power)
```

```
def function_volt_all(book_name):
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    volt_sheets = []
    for volt in loads:
        sheet = str(volt) + ' Bus Voltage'
        volt_sheets.append(sheet)
    volt_df_list = []
    for volt_sheet in volt_sheets:
        df = function_volt_desired(book_name, volt_sheet)
        df['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(volt_sheet.split(' ')[0])/20
                                                            ))),2))# the book_name used here
        volt_df_list.append(df)
    df_volt= pd.concat(volt_df_list).reset_index(drop=True)
    return df_volt
```

## 4.9 Python Functions to extract bus voltages for desired incremental transfer

```
def function_volt_desired(book_name, sheet, desired_incremental_transfer):
    import numpy as np
    """
    inputs: book_name, sheet
            book_name -> the obtained PV Excel file (.xlsx file type)
            sheet -> sheet name in the Excel file ('string')
            desired_incremental_transfer -> desired incremental transfer in MW (int)
    output: dataframe -> dataframe corresponind to the load (DataFrame)
    """
    data = pd.read_excel(book_name, sheet_name=sheet, header=1)
    data_bus = data.iloc[:,:2]
    data_bus[[data_bus.columns[0], data_bus.columns[1]]] = data_bus[[data_bus.columns[0],data_bus.
                                                        columns[1]]].astype(str)
    data['Bus Voltage'] = data_bus[[data_bus.columns[0],data_bus.columns[1]]].agg(' '.join, axis=1
                                                        )
    data_power = data

    if desired_incremental_transfer in data_power:
        data_power = data[['Bus Voltage',desired_incremental_transfer]]
        col = list(data_power.columns)
        desired_incremental_transfer = col[1]
        data_power = data_power[['Bus Voltage',desired_incremental_transfer]]
        new_bus_name = 'Bus Voltage for incremental transfer of '+ str(
                                                            desired_incremental_transfer) + ' MW'
        data_power = data_power.rename(columns={data_power.columns[1]:new_bus_name})
    else:
        data_power[desired_incremental_transfer] = np.nan
        data_power = data_power[['Bus Voltage',desired_incremental_transfer]]
        new_bus_name = 'Bus Voltage for incremental transfer of '+ str(
                                                            desired_incremental_transfer) + ' MW'
        data_power = data_power.rename(columns={data_power.columns[1]:new_bus_name})
```

```
    return data_power
```

```
def function_volt_all(book_name, desired_flow):
    loads = [39.69,34.64,30.36,26.66,23.38,20.40,17.63,15,12.39,10.79,9.68,0]
    volt_sheets = []
    for volt in loads:
        sheet = str(volt) + ' Bus Voltage'
        volt_sheets.append(sheet)
    volt_df_list = []
    for volt_sheet in volt_sheets:
        df = function_volt_desired(book_name, volt_sheet, desired_flow)
        df['Load PF'] = 'PF = ' + str(round(math.cos((math.atan(float(volt_sheet.split(' ')[0])/20
                                                            ))),2))# the book_name used here
        volt_df_list.append(df)
    df_volt= pd.concat(volt_df_list).reset_index(drop=True)
    return df_volt
```