Power Factor Correction:

Lab 2

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Abstract

Power Factor is the ratio between the useful (true) power (kW) to the total (apparent) power (kVA) consumed by an item of a.c. electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand. All current flow causes losses both in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply. A load with a power factor of, say, 0.8, results in much higher losses in the supply system and a higher bill for the consumer. A comparatively small improvement in power factor can bring about a significant reduction in losses since losses are proportional to the square of the current

Often in Power Systems, there is a need for Power Factor Correction, this is just the process of compensating for the lagging current by creating a leading current by connecting capactive reactance to the system. These capacitive loads include static capacitors, synchronous condensers, and phase advansers all of which just compensate for the lagging current caused by the inuductiveness of the power systems.

Shunt capacitors are an integral part of a power system because it balances power transmission issues such as low voltage regulation, poor reliability, and of course the power factor.

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1 Introduction

For this lab, students use capacitor banks to correct the power factor of a three-phase inductive load. Students learn how power factor correction changes line current magnitude through reduction of reactive power transfer from source to load. Students also design and demonstrate a power factor correction function that returns the capacitive reactance required to correct an inductive load over a constrained range of real and reactive load values. Objectives Students learn how capacitors are used to correct the power factor of an inductive load. As capacitive reactance is added to a load bus, students should observe:

- the load power factor angle shift
- a change in the reactive power provided by the power supply
- a change in the line current magnitude serving the load

Data analysis and interpretation, drawing conclusions Design a power factor correction function that calculates required reactive power for a given load

2 Part 1: Circuit Build and Data Gathering

The circuit build consisted of two Wye-connected load with the following impedances Case 1: Z_L = 600 Ω and Case 2: Z_L = 300 + j300 Ω
For each case a sweep was done a series of capacitive impedances
X_C = -[171, 200, 240, 300, 400, 600, 1200, open] Ω

Using the LVDACS meters, phasor analyzer and the oscilloscope to record the data that is shown below.

Table 1: Measured data values from Lab Session Case 1

Capacitance	Current 1	Real Power	Reactive Power	Power Factor	I1 Phase	Apparent Power
-171j	0.771	24.15	-84.47	0.262	74.13	92.17
-200j	0.672	23.55	-71.82	0.293	71.83	80.38
-240j	0.569	23.44	-59.46	0.344	68.36	68.14
-300j	0.475	23.59	-47.64	0.414	63.60	56.98
-400j	0.384	23.69	-36.15	0.516	56.55	45.91
-600j	0.297	23.78	-24.36	0.668	45.66	35.60
-1200j	0.232	23.77	-11.78	0.852	26.63	27.90
Open	0.199	23.83	0.003	1	0.09	23.83

Table 1 shows that measured obtained values [Voltage, Current, Real Power (P), Reactive Power (Q), I1 Phase and the calculated Apparent Power] of the first case.

Table 2: Measured Values from Lab Session Case 2

Capacitance	Current 1	Real Power	Reactive Power	Power Factor	I1 Phase	Apparent Power
300+300jll-171j	0.599	23.63	-61.24	0.332	68.84	71.17
300+300jll-200j	0.507	23.30	-49.09	0.386	64.37	60.36
300+300jll-240j	0.415	23.09	-36.87	0.468	57.58	49.34
300+300jll-300j	0.596	23.58	-25.64	0.596	47.20	39.56
300+300jll-400j	0.262	23.41	-13.78	0.750	30.38	31.21
300+300jll-600j	0.217	23.64	-2.167	0.917	05.15	25.78
300+300jll-1200j	0.219	23.65	9.914	0.905	-22.91	26.13
Open	0.270	23.69	21.75	0.736	-42.59	32.19

Table 2 shows that measured obtained values [Voltage, Current, Real Power (P), Reactive Power (Q), I1 Phase and the calculated Apparent Power] of the second case.

3 Part 2.1: Data Analysis and Interpretation, Drawing Conclusions

Calculate S_L for each case

S_L = P/PF

Table 3: Measured and Calculated values of apparent power

Measured Values:			Calculated Values:		
	Case 1	Case 2		Case 1	Case 2
Capacitance	S1	S2	Capacitance	S1	S2
-171j	92.17	71.17	-171j	87.56	64.82
-200j	80.38	60.36	-200j	75.89	53.67
-240j	68.14	49.34	-240j	64.62	43.27
-300j	56.98	39.56	-300j	53.67	33.94
-400j	45.91	31.21	-400j	43.27	26.83
-600j	35.60	25.78	-600j	33.94	24.00
-1200j	27.90	26.13	-1200j	26.83	26.83
Open	23.83	32.19	Open	24.00	33.94

Q_C ranges from -84.47 to 0.003 VAR (reference Figure 4)

Calculating all expected S_{Total}

$$S_{Total} = 3S_L$$

Calculating I_{line}

$$I_{line} = V/Z_L$$

On the following plots, the open Q_C value was input as -2000 in order to make the plots appear more reasonable. The value of the curve on the far right is it's value when Qc = 0.

Case 1:

V_{bus} stays constant as Q_C varies.

In case 1, we looked at the system with an increasing inductive load.

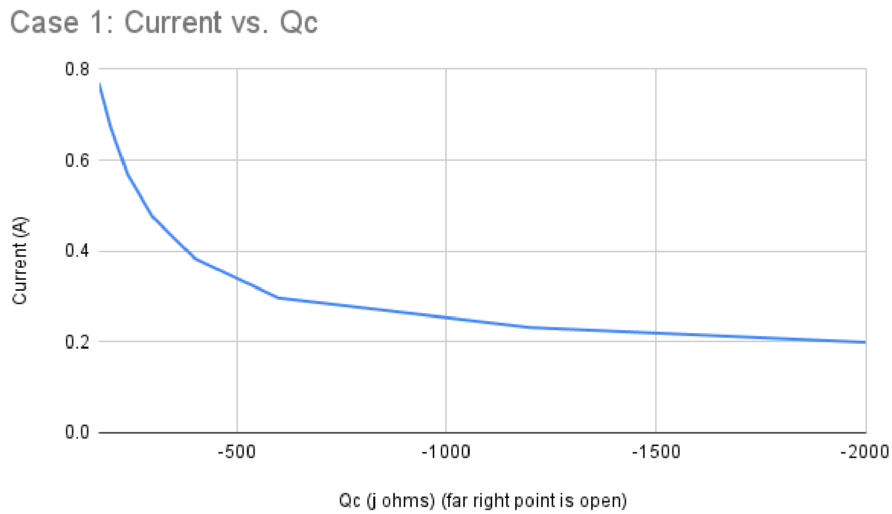

Figure 1: Case 1 Current vs. Qc

In Figure 1, we can see that as the inductive load increases, the current has an exponential decay that has a horizontal asymptote around 0.2A. So the current decreases to around 0.2A.

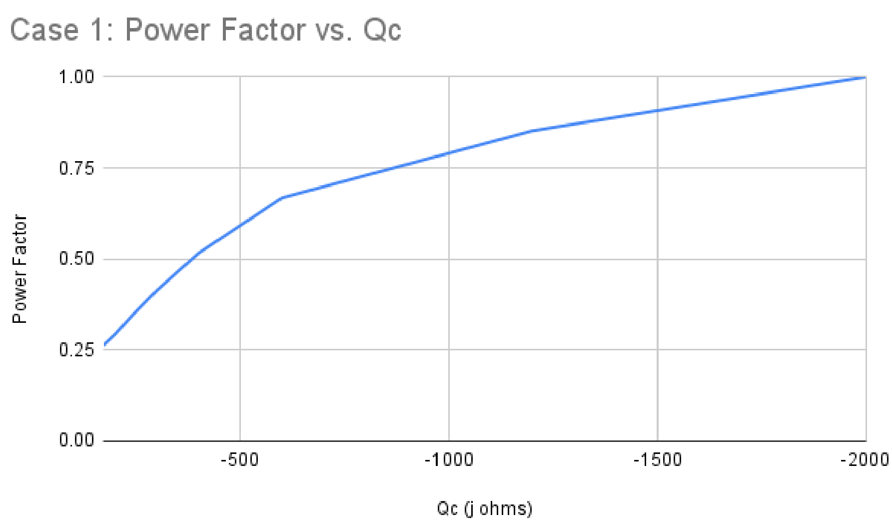

Figure 2: Case 1 Power Factor vs. Qc

In Figure 2, we can see that as the inductive load increases, the power factor increases (decreasing exponentially though) to a PF of 1.

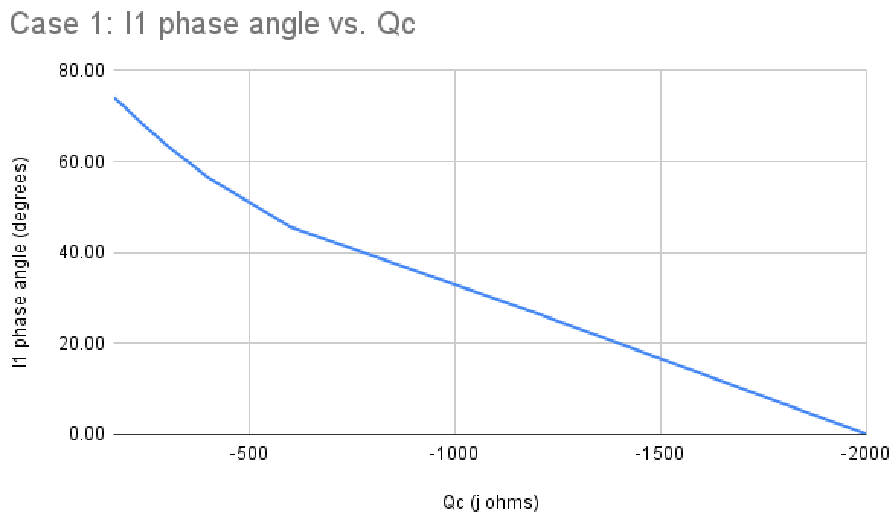

Figure 3: Case 1 I1 phase angle vs. Qc

In Figure 3, we can see that as the inductive load increases the phase angle approaches 0 in a semi-linear fashion toward a 0 degree phase angle.

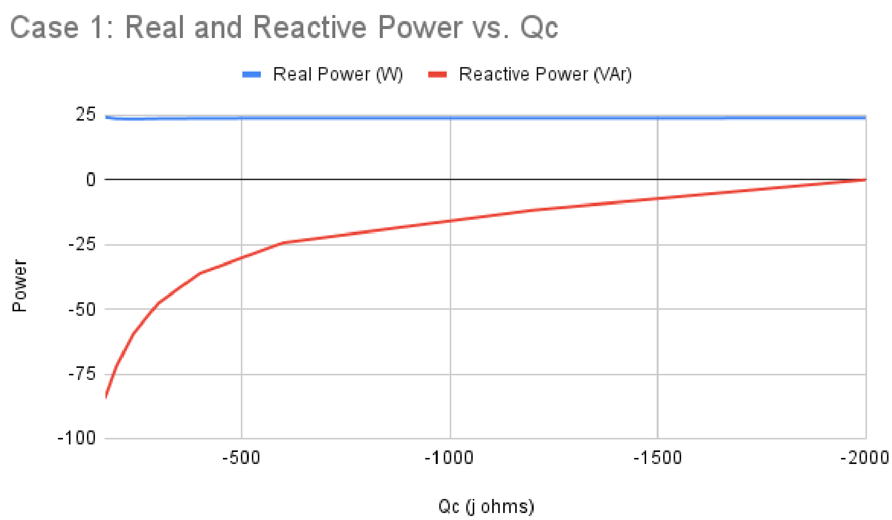

Figure 4: Case 1 Real and Reactive Power vs. Qc

In Figure 4, we can see that as the inductive load increases we see an exponential decay relationship for the reactive power, that approaches 0.

Case 2:

In Case 2, we looked at the system with a decreasing inductive load and a consistent capacitive load.

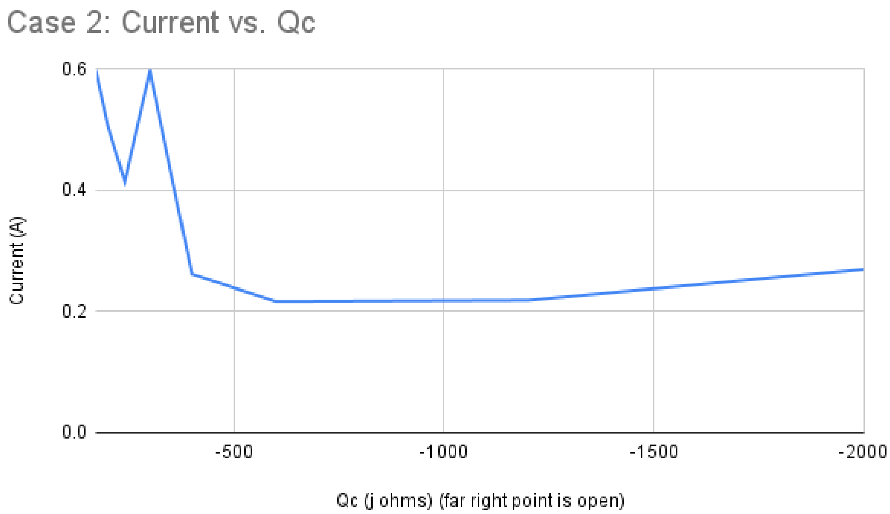

Figure 5: Case 2 Current vs. Qc

In Figure 5, if we ignore the anomaly in the data, we can see that as the inductive load increases, the current decreases but then once the inductive load passes a certain point the current starts to slowly rise.

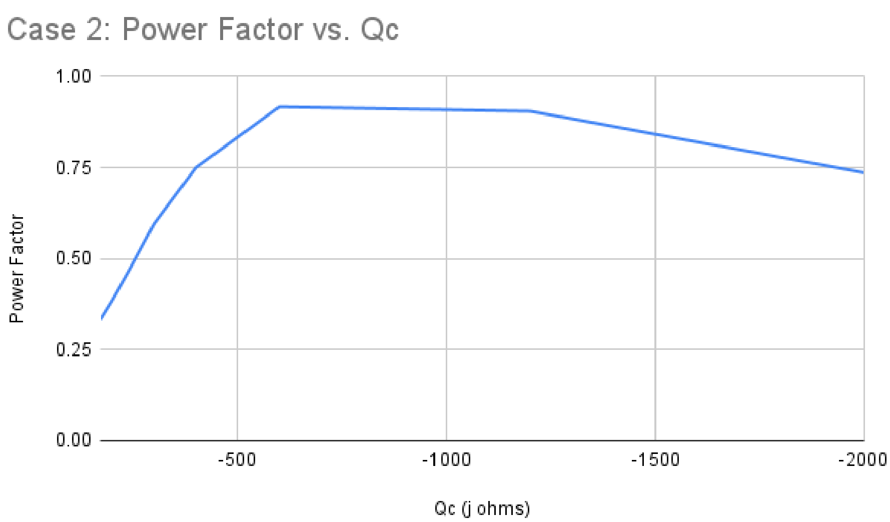

Figure 6: Case 2 Power Factor vs. Qc

In Figure 6, we can see that as the inductive load increases, the power factor increases but then starts to fall back down around 0.9-0.95 PF.

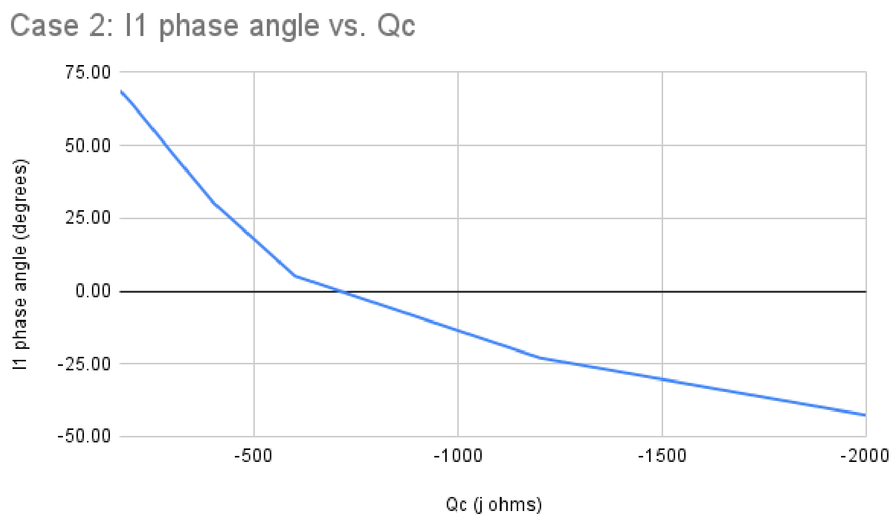

Figure 7: Case 2 I1 phase angle vs. Qc

In Figure 7, we can see that the relationship between the phase angle and Qc, is that as the inductive load increases, the phase angle decreases, except this time to a negative angle due to the capacitive load causing the current to lead voltage in the circuit. Also the data shows that there is again an offset of the phase angle from Figure 3 to Figure 7.

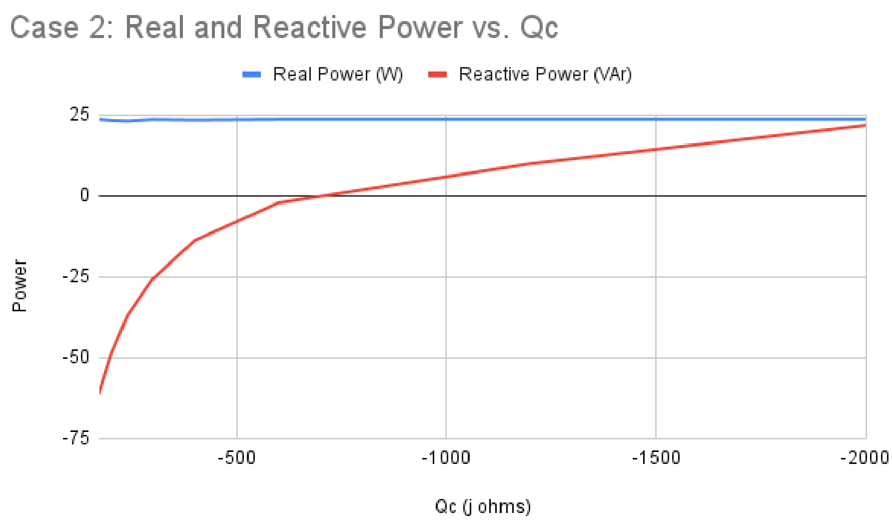

Figure 8: Case 2 Real and Reactive Power vs. Qc

In Figure 8, we can see that the only difference from Figure 4, is that the reactive power has an offset of about 25VAR, which makes sense due to the added Capacitive load.

4 Part 2.2: Engineering Design

This program was built using a brute-force method. It wasn't until later that we determined that a simple relationship appears from the plotting of the measured data: $PF \geq 0.95$ corresponds with a $(Q_C + Q_L) \leq 0.333P_L$.

The code listed below tests the function for 100 P values and 100 Q values for a total of 10000 possible combinations, to get a fine resolution. The output of a single fuction call is a single value of the appropriate Q_C to bring the power factor to at least 0.95.

4.1 User guide

This section details a program that takes two real-valued floating point numbers interpreted as P and Q (real and reactive power, respectively), in that order, and returns a corresponding Qc value to correct the power factor to 0.95. Q_c is returned as a negative value in increments of 0.25. The program was tested using the given range of input: $S = P + jQ = [1 + j0 : 10 + j10]VAR$

To use the function in python, call it as

```
pf_correction(p,q)
```

with p = a real floating point value for real power in MW, and q = a real floating point value for reactive power in MVAr. The output will be in this format if the given values do not require PF correction (i.e. PF = 0.95 or above already),

```
P = 10.0, Q = 3.23
S_mag = 1.1e+01          pf = 0.95
Qc to add = 0.0 MVAr
```

and in this format if the given values require PF correction:

```
pf correction
started with S = [10.0 + j3.33] MVA
```

```
The following values yield a pf >= 0.95:
S = [10.0 + j3.08] MVA
PF = 0.96
Qc to add = -0.25 MVAr
```

4.2 Python code:

```
# EE347 Lab 2
# Team 2:
# 2.2 Engineering Design

import math
import numpy as np

N = 100                         # NxN possible combinations
pf_cutoff = 0.95                # pf should be at or above this value
P = np.linspace(1,10,N)         # N evenly spaced values btwn 1 and 10
Q = np.linspace(0,10,N)         # N evenly spaced values btwn 0 and 10
qc_step = .25                   # discrete values of Qc with this step size
Qc = np.arange(0,-N,-qc_step)# N possible values of Qc btwn 0 and -N*qc_step
q_add = 0.                      # initiate variable to store correcting qc in

# function definition
# takes a given p and q and returns a corresponding correcting capacitance, qc
def pf_correction(p,q):
    S_mag = math.sqrt(p**2+q**2)      # |S| = sqrt(p^2 + q^2)
    pf = p/S_mag        # uncorrected pf

    # q_target is the value of q that gives pf = 0.95 for the given value of p
    q_target = p*math.tan(math.acos(pf_cutoff))

    # if the given pf is already above 0.95, then qc = 0
```

```
    if pf >= pf_cutoff:
        # output the values for confirmation
        print(f"P = {p:.3}, Q = {q:.3}")
        print(f"S_mag = {S_mag:.2}     \t pf = {pf:.2}")

        # qc = 0
        return 0.

    # if pf is not >= 0.95, then it needs correction
    else:
        # iterate through possible qc values (increment 0.25)
        for qc in Qc:
            q_nu = q + qc
            if q_nu <= q_target:
                S_mag = math.sqrt(p**2+q_nu**2)
                pf = p/S_mag

                print("\npf correction")
                print(f"started with S = [{p:.3} + j{q:.3}] MVA")
                print(f"The following values yield a pf >= {pf_cutoff:.2}:")
                print(f"S = [{p:.3} + j{q_nu:.3}] MVA")
                print(f"PF = {pf:.2}")

                # return qc correction
                return qc

# test NxN possible values in the given range
# for each p, iterate through every q
for p in P:
    for q in Q:
        q_add = pf_correction(p,q)
        print(f"Qc to add = {q_add:.3} MVAr")
```

We were not able to get a clear plot from using this code, which is likely due to the fact that it wasn't written in a vectorized format.

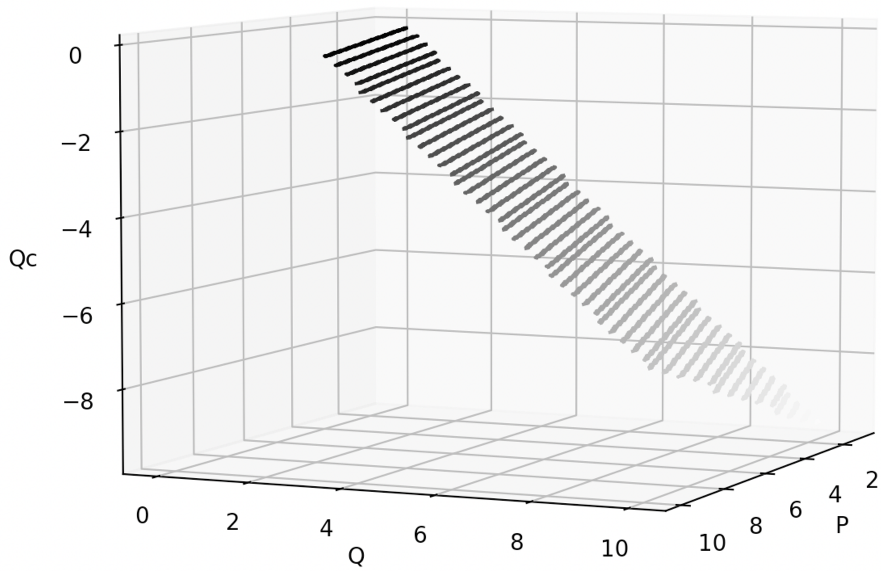

Figure 9: Values of Qc from given P and Q

5 Conclusion

In this lab, we learned the effect of capacitive and inductive loads on a power system, with respect to reactive power, current, phase angle, real power, and power factor. These factors of the power system all have a pretty distinct relationship with respect to the inductive load being increased and a very consistent offset theme to when capacitve loads are introduced.

A Appendix:

Unimportant stuff you really can't get yourself to believe is unimportant ...

References

Authors

Nick Porter, is a BS candidate in the Electrical & Computer Engineering department at Portland State University. He has started a focus on signal processing, but maintains an interest in power transmission, especially with the growing use of automation for smart grids

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YES

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