UTILIZATION OF ELECTRICAL ENERGY

Assist. Prof.Dr. Oğuzhan TİMUR
Department of Electrical & Electronics Engineering
2020

UTILIZATION OF ELECTRICAL ENERGY

Assist. Prof.Dr. Oğuzhan TİMUR
Department of Electrical & Electronics Engineering
2020

EEE 317 Utilization of Electrical Energy, Week 06

Power Calculations in AC

Single Phase (1Ø) Power Calculation

SUMMARY

$v(t) = V_m \cos(wt + \theta_v)$
$i(t) = I_m \cos(wt + \theta_i)$

Instantaneous power $\rightarrow$ p(t) = v(t).i(t)

Instantaneous power

$$p(t) = \frac{V_m I_m}{2}\left[\cos(\theta_v - \theta_i) + \cos(2wt + \theta_v + \theta_i)\right]$$

Real power/Active Power/Average Real Power

$$P = \frac{V_m I_m}{2}\cos(\theta_v - \theta_i) \text{ or } P = V_{rms} I_{rms} \cos(\theta_v - \theta_i)$$

Reactive Power

$$P = \frac{V_m I_m}{2}\sin(\theta_v - \theta_i) \text{ or } P = V_{rms} I_{rms} \sin(\theta_v - \theta_i)$$

Power Factor

$pf = \cos(\theta_v - \theta_i)$

Reactive Factor

$rf = \sin(\theta_v - \theta_i)$

Complex Power

$S = P + jQ$

$S = |I_{rms}|^2 Z = P + jQ$

$$S = \frac{|V_{rms}|^2}{Z^*} = P + jQ$$

Apparent Power

$|S| = \sqrt{P^2 + Q^2}$

Power Calculations in AC

Three Phase (3Ø) Power Calculation

SUMMARY

$P = \sqrt{3} V_L I_L \cos(\theta_v - \theta_i)$ Real (Active) Power

$Q = \sqrt{3} V_L I_L \sin(\theta_v - \theta_i)$ Reactive Power

$S = P + jQ = \sqrt{3} V_L I_L \angle(\theta_v - \theta_i)$ Complex Power

Total Complex Power

$$S = 3S_p = 3V_p I_p^* = 3|I_p|^2 Z_p = \frac{3|V_p|^2}{Z_p^*}$$

$$S = P + jQ = \sqrt{3} V_L I_L \angle\theta$$

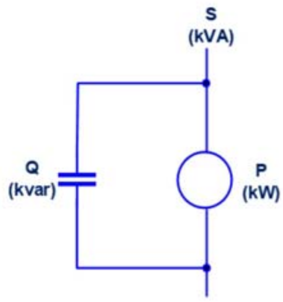
V_p, I_p, V_L and all rms values

Reactive Power Compensation

Reactive Energy and Power Factor

Alternating current systems supply two forms of energy:

- **"Active" energy** measured in kilowatt hours (kWh) which is converted into mechanical work, heat, light, etc.
- **"Reactive" energy,** which again takes two forms:
  - "Reactive energy" required by inductive circuits (transformers,motors,etc.)
  - "Reactive" energy required by capacitive circuits (cable capacitance, power capacitors, etc.)

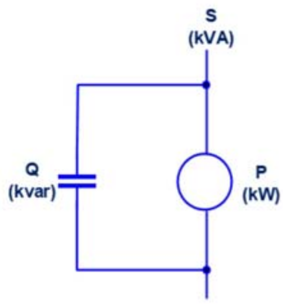


Reactive Power Compensation

Reactive Energy and Power Factor

All inductive (i.e. electromagnetic) machines and devices that operate on AC systems convert electrical energy from the power system generators into mechanical work and heat.

This energy is measured by kWh meters, and is referred to as **"active" or "wattful"** energy. In order to perform this conversion, magnetic fields have to be established in the machines, and these fields are associated with another form of energy to be supplied from the power system, known as **"reactive" or "wattless"** energy.



Reactive Power Compensation

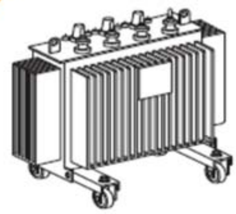
Reactive Energy and Power Factor

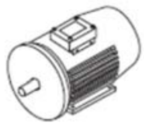
All AC plant and appliances that included electromagnetic devices, or depend on magnetically-coupled windings, require some degree of reactive current to create magnetic flux.

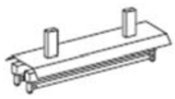
The most common items in this class are transformers and reactors,motors and discharge lamps (i.e. The ballasts of them)

The proportion of reactive power (kvar) with respect to active power (kW) when an item of plant is fully loaded varies according to the item concerned being:

- 65-75 % for asynchronous motors
- 5-10% for transformers







Reactive Power Compensation

Reactive Energy and Power Factor

Definition of power factor

- The **power factor** of load, which may be a single power-consuming item, or a number of items (for example an entire installation, is given **by the ratio of Active Power(P) to Apparent Power (S) i.e.** kW divided by kVA at any given moment.
- The value of a power factor will range **from 0 to 1.**
- If current and voltages are perfectly sinusoidal signals, **power factor equals cosø**
- A power factor close to unity means that reactive energy is small compared with the active energy, while a low value of power factor indicates the opposite condition.

Reactive Power Compensation

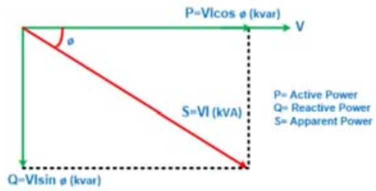
Reactive Energy and Power Factor

Power Vector Diagram

- **Active power P (in kW)**
  - Single phase (1 phase and neutral): P=VxIxcos ø
  - Single phase (phse to phase): P=UxIxcos ø
  - Three phase (3 wires or 3 wires + neutral): P= √3xUxIxcos ø
- **Reactive Power Q (in kvar)**
  - Single Phase (1 phase and neutral): P=VxIxsin ø
  - Single phase (phase to phase): Q=UIsin ø
  - Three phase (3 wires or 3 wires+neutral): P= √3xUxIxsin ø
- **Apparent Power S (in kVA)**
  - Single phase (1 phase and neutral): S=VI
  - Single phase (phase to phase): S=UI
  - Three phase (3 wires or 3 wires+neutral): P= √3xUxI where:
    V= Voltage between phase and neutral
    U= Voltage between phases
  - For balanced and near-balanced loads on 4-wire systems

The power factor is **the ratio of kW to kVA**. The closer the power factor approaches its maximum possible value of 1, the greater the benefit to consumer and supplied.

PF= P(kW)/S(kVA)
P= Active Power
S= Apparent Power



Reactive Power Compensation

Reactive Energy and Power Factor

Type of circuit	Apparent Power S (kVA)	Active Power P= (kW)	Reactive Power Q (kvar)
Single-phase (phase and neutral)	S=VI	P=VIcos ø	Q=VIsin ø
Single phase (phase to phase)	S=UxI	P=UIcos ø	Q=UIsin ø
Ex: 5 kW of load cos ø=0.5	10 kVA	5 kW	8,7 kVAR
Three phase 3-wire or 3 wire+ neutral	S=√3xUxI	P=√3xUxIxcosø	Q=√3xUxIxsin ø
Ex: Motor Pn=51 kW cos ø=0.86 Efficiency(motor)=0,91	65 kvA	56 kW	33 kVAR

Example in the calculation of active and reactive power

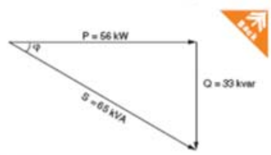


Fig. K5 : Calculation power diagram

Practical values of power factor
The calcultaions for the three-phase example above are as follows:
Pn=delivered shaft power= 51 kW

P=active power consumed= Pn/P=51/0.91=56 kW

S=apparent power= P/cos ø=56/0,86=65 kVA

So that, **Q=P.tan ø**=56x0,59=33kVAR

Alternatively

$$Q^2 = \sqrt{S^2 - P^2} = \sqrt{65^2 - 56^2}$$

$$Q^2 = \sqrt{(65-56)(65+56)} = \sqrt{(9)(121)}$$

$$Q = 33kVAR$$

Reactive Power Compensation

Plant and appliances		cos ø	tan ø
▪ common loaded at induction motor	0%	0,17	5,80
	25 %	0,55	1,52
	50 %	0,73	0,94
	75 %	0,80	0,75
	100 %	0,85	0,62
▪Incandascent lamps		1,0	0
▪Fluorescent lamps (uncompensated)		0,5	1,73
▪Fluorescent lamps (compensated)		0,93	0,39
▪Discharge lamps		0,4 to 0,6	2,29 to 1,33
▪ Ovens using resistance elements		1,0	0
▪ Induction heating ovens (compensated)		0,85	0,62
▪ Dielectric type heating ovens		0,85	0,62
▪ Resistance-type soldering machines		0,8 to 0,9	0,75 to 0,48
▪ Fixed 1-phase arc-welding set		0,5	1,73
▪ Arc-welding motor-generating set		0,7 to 0,9	1,02 to 0,48
▪ Arc-welding transformer-rectifier ser		0,7 to 0,8	1,02 to 0,75
▪ Arc furnace		0,8	0,75

Values of cos ø and tan ø for commonly-used plant and equipment

Reactive Power Compensation

Why is the power factor improved?

1. Reduction in the cost of electricity

Good management in the construction of reactive energy brings with it the following economic advantages.

These notes are based on an actual tariff structure of a kind commonly applied in Europe, designed to encourage consumers **to minimize their consumption of reactive energy.**

The installation of power-factor correcting capacitors on installations permits the consumer to **reduce his electricity bill** by maintaining the level of reactive-power consumption below a value constructually agreed with the power supply authority. In this particular tariff, reactive energy is billed according to the tan ø criterion

As previously noted:

$$\tan \emptyset = \frac{Q\ (kVarh)}{P(kWh)}$$

Reactive Power Compensation

Why is the power factor improved?

2. Technical/economic optimization

A higher power factor allows the optimization of the components of an installation. Overheating of certain equipment can be avoided, but to achieve the best results, the correction should be effected as close to the individual items of inductive plant as possible.

a. Reduction of cable size

Table shows the required increase in the size of cables as the power factor is reduced from unity to 0.4.

Multiplying factor for the cross-sectional area of the cable core(s)	1	1,25	1,67	2,5
cos ø	1	0,8	0,6	0,4

Multiplying factor for cable size as a function of cos ø

Reactive Power Compensation

Why is the power factor improved?

b. Reduction of losses (P,kW) in cables

Losses in cables are proportional to the current squared, and are measured by the kWh meter for the installation. Reduction of the total current in a conductor by 10% for ex., will reduce the losses by almost 20%.

c. Reduction of voltage drop

Power factor correction capacitors reduce or even cancel completely the (inductive) reactive current in upstream conductors, thereby reducing or eliminating voltage drops.

Note: Overcompensation will produce a voltage rise at the capacitors.

d. Increase in available power

By improving the power factor of a load supplied from a transformer, the current through the transformer will be reduced, thereby allowing more load to be added. In practice, it may be less expensive to improve the power pactor, than to replace the transformer by a larger unit.

Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

Improving the power factor of an installation requires a bank of capacitors which acts as a source of reactive energy. This arrangement is said to provide reactive energy compensation.

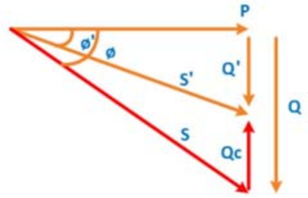
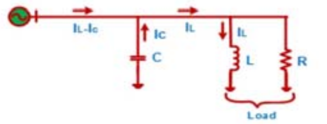
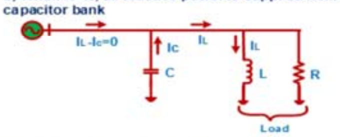


Diagram showing the principle of compensation:
$Q_c = P(\tan ø - \tan ø')$

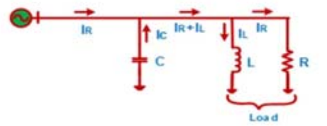
a) Reactive current components only flow pattern



b) When Ic=IL, all reactive power is supplied from the capacitor bank



b) With load current added to case (b)



Showing the essential features of power-factor correction

Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

Example: A motor consumers 100 kW at a power factor of 0.75 (i.e. tan ø=0.88). To improve the power factor to 0.93 (i.e. tan ø =0.4),
Answer : The reactive power of the capacitor bank must be: Qc=100(0.88-0.4)=48 kVAR

By using what Equipment?

Compensation at LV

At low voltage, compensation is provided by:

- **Fixed-valued capacitor**
- **Equipment providing automatic regulation, or banks** which allow continuous adjustment according to requirements, as loading of the installation changes

Note: When the installed reactive power of compensation exceeds 800 kVAR, and the load is continuous and stable, it is often found to be economically advantageous to install capacitor banks at high voltage.

Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

Fixed capacitors

This arrangement employs one or more capacitor(s) to form a constant level of compensation. Control may be:

- Manual: by circuit breaker or load-break switch
- Semi-automatic: by contactor
- Direct connection to an appliance and switched with it

These capacitors are applied:

- At the terminals of inductive devices (motors and transformers)
- At busbars supplying numerous small motors and inductive appliance for which individual compensation would be too costly
- In cases where the level of load is reasonably constant

Example of fixed-value compensation capacitors

Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

Automatic capacitor banks

This kind of equipment provides automatic control of compensation, maintaining within close limits, a selected level of power factor. Such equipment is applied at points in an installation where the active-power and/or reactive-power variations are relatively large, for example

- At the busbars of a general power distribution board
- At the terminals of a heavily-loaded feeder cable

Example of automatic-compensation-regulating equipment

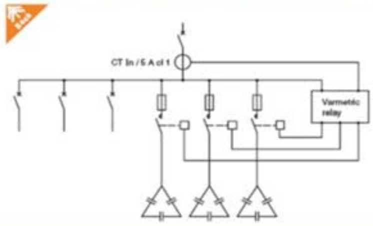
Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

The principles of, and reasons, for using automatic compensation

A bank of capacitors is divided into a number of sections, each of which is **controlled by a contactor**. Closure of a contactor switches its section into parallel operation with other sections already in service. The size of the bank can therefore be increased or decreased in steps, by the closure and opening of the controlling contactors.

A control relay monitors the power factor of the controlled circuit(s) and is arranges to close and open appropriate contactors to maintain a reasonably constant system power factor (within the tolerance imposed by the size of each step of compensation). The current transformer for the monitoring relay must evidently be placed on one phase of the incoming cable which supplies the circuit(s) being controlled, as shown in Figure.



The principle of automatic-compensation control

Reactive Power Compensation

HOW TO IMPROVE POWER FACTOR?

The choice between a fixed or automatically-regulated bank of capacitors

Commonly-applied rules

Where the kvar rating of the capacitors is **less than, or equal to 15%** of the supply transformer rating, **a fixed value of compensation** is appropriate. **Above the 15% level**, it is advisable to install **an automatically-controlled bank of capacitors**. The location of low-voltage capacitors in an installation constitutes the mode of compensation, which may be global (one location for the entire installation), partial (section-by-section), local (at each individual device), or some combination of the latter two. In principle, the ideal compensation is applied at a point of consumption and at the level required at any instant.

In practice,technical and economic factors govern the choice.

Reactive Power Compensation

Where to installation of correction capacitors

1. Global Compensation

Principle

The capacitor bank is connected to the busbars of the main LV distribution board for the installation, and remains in service during the period of normal load.

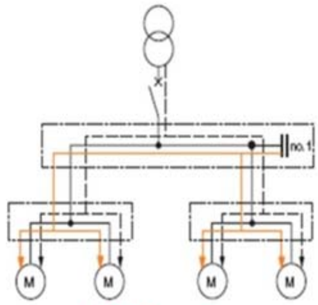
Advantages

The global type of compensation:

❑ Reduces the tariff penalties for excessive consumption of kVARs
❑ Reduces the apparent power kVA demand, on which standing charges are usually based
❑ Relieves the supply transformer, which is then able to accept more load if necessary

Comments

❑ Reactive current still flows in all conductors of cables leaving (i.e. Downstream of) the main LV distribution board
❑ For the above reason, the sizing of these cables, and power losses in them, are not improved by the global mode of compensation.



Global Compensation

Reactive Power Compensation

2. Compensation by sector

Principle

Capacitor banks are connected to busbars of each local distribution board.A significant part of the installation benefits from this arrangement, notably the feeder cables from the main distribution board to each of the local distribution boards at which the compensation measures are applied.

Advantages

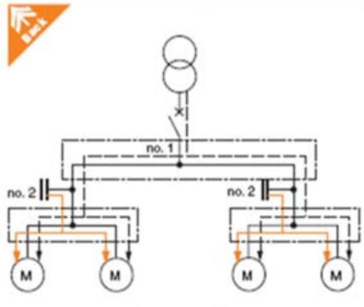
The compensation by sector:

❑ Reduces the tariff penalties for excessive consumption of kVARs
❑ Reduces the apparent power kVA demand, on which standing charges are usually based
❑ Relieves the supply transformer, which is then able to accept more load if necessary
❑ The size of the cables supplying the local distribution boards may be reduced, or will have additional capacity for possible load increases
❑ Losses in the same cables will be reduced

Comments

❑ Reactive current still flows in cables downstream of the local distribution boards
❑ For the above reason, the sizing of these cables, and power losses in them, are not improved by compensation by sector.
❑ Where large changes in loads occur, there is always a risk of overcompensation and consequent overvoltage problems

Compensation by sector is recommended When the installation is extensive, and where the load/time patterns differ from one part of the installation to another



Compensation by sector

Reactive Power Compensation

3. Individial compensation

Principle

Capacitors are connected directly to the terminals of inductive plant (notably motors). Individual compensation should be considered when the power of the motor is significant with respect to the declared power requirement (kVA) of the installation.

The kVAR rating of the capacitor bank is in the order of 25% of the kW rating of the motor. Complementary compensation at the origin of the installation (transformer) may also be beneficial.

Advantages

Individial compensation:

- ❑ Reduces the tariff penalties for excessive consumption of kVARs
- ❑ Reduces the apparent power kVA demand,
- ❑ Reduces the size of all cables as well as the cable losses.

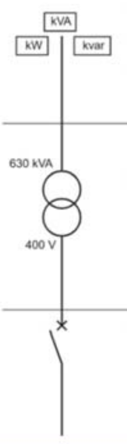
Comments

- ❑ Significant reactive currents no longer exist in the installation.

Reactive Power Compensation

Installation before P.F. correction

$\overrightarrow{kVA} = \overrightarrow{kW} + \overrightarrow{kvar}$ [a]



- kvarh are billed heavily above the declared level
- Apparent power kVA is significantly greater than the kW demand
- The corresponding excess current causes losses (kWh) which are billed
- The installation must be over-dimensioned

Characteristics of the installation

500 kW cos φ = 0.75

- Transformer is overloaded
- The power demand is

$$S = \frac{P}{\cos\varphi} = \frac{500}{0.75} = 665 \text{ kVA}$$

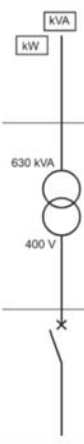
S = apparent power

- The current flowing into the installation downstream of the circuit breaker is

$$I = \frac{P}{\sqrt{3}U\cos\varphi} = 960 \text{ A}$$

Installation after P.F. correction

$\overrightarrow{kVA} = \overrightarrow{kW} + \overrightarrow{kvar}$



- The consumption of kvarh is
  - Eliminated, or
  - Reduced, according to the cos φ required
- The tariff penalties
  - For reactive energy where applicable
  - For the entire bill in some cases are eliminated
- The fixed charge based on kVA demand is adjusted to be close to the active power kW demand

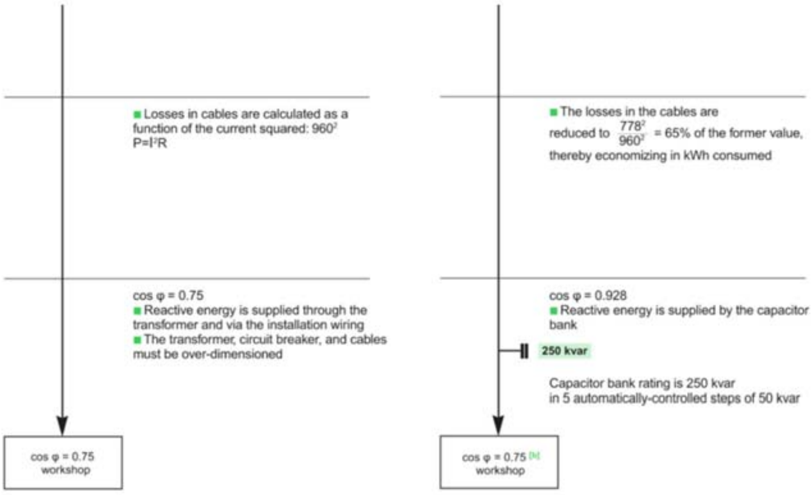
Characteristics of the installation

500 kW cos φ = 0.928

- Transformer no longer overloaded
- The power-demand is 539 kVA
- There is 14% spare-transformer capacity available

- The current flowing into the installation through the circuit breaker is 778 A

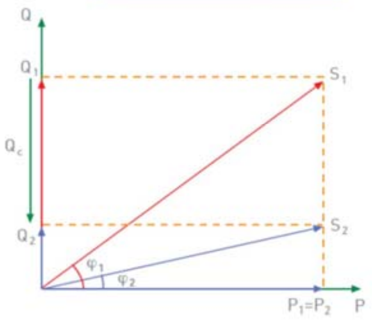
Reactive Power Compensation



Reactive Power Calculation

First Method

Using of Power Triangle



$$Q_1 = S_1.\sin\varphi_1$$
$$Q_2 = S_2.\sin\varphi_2$$
$$Q_c = Q_1 - Q_2$$
$$Q_c = S_1.\sin\varphi_1 - S_2.\sin\varphi_2$$
$$P_1 = S_1.\cos\varphi_1 \rightarrow S_1 = \frac{P_1}{\cos\varphi_1}$$
$$P_2 = S_2.\cos\varphi_2 \rightarrow S_2 = \frac{P_2}{\cos\varphi_2}$$
$$Q_c = S_1.\sin\varphi_1 - S_2.\sin\varphi_2$$
$$Q_c = \frac{P_1}{\cos\varphi_1}\sin\varphi_1 - \frac{P_2}{\cos\varphi_2}\sin\varphi_2$$
$$P = P_1 = P_2$$
$$Q_c = P_1(\tan\varphi_1 - \tan\varphi_2)$$

[10]

Second Method

Using of Coefficient Table

According to Load

for example

load $\rightarrow$ P=750 kW

measured power factor $\rightarrow \cos\varphi_1 = 0.70$

desired power factor $\rightarrow \cos\varphi_2 = 0.98$

from the table $\rightarrow$ coefficient=0.817

$Q_c = P.coefficient = 750kW.(0.817)$

$Q_c = 612.75kVAR$ is obtained

According to Transformer Power

for example

TransformerPower $\rightarrow$ P=1000kVA

Rated load to TR power % $\rightarrow$ 75%

measured power factor $\rightarrow \cos\varphi_1 = 0.70$

desired power factor $\rightarrow \cos\varphi_2 = 0.98$

from the table $\rightarrow$ coefficient=0.817

$Q_c = S.\%.\cos\varphi_1.coefficient = 1000.(0.75).(0.7).(0.817)$

$Q_c = 428.925kVAR$ is obtained

Güç Faktörü		Yük için kW başına gereken reaktif güç [kVAr] katsayı tablosu										
Cosφ		0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
	tgφ	0.484	0.456	0.426	0.395	0.363	0.329	0.292	0.251	0.203	0.142	0.000
0.40	2.291	1.807	1.836	1.865	1.896	1.928	1.963	2.000	2.041	2.088	2.149	2.291
0.41	2.225	1.740	1.769	1.799	1.829	1.862	1.896	1.933	1.974	2.022	2.082	2.225
0.42	2.161	1.676	1.705	1.735	1.766	1.798	1.832	1.869	1.910	1.958	2.018	2.161
0.43	2.100	1.615	1.644	1.674	1.704	1.737	1.771	1.808	1.849	1.897	1.957	2.100
0.44	2.041	1.557	1.585	1.615	1.646	1.678	1.712	1.749	1.790	1.838	1.898	2.041
0.45	1.985	1.500	1.529	1.559	1.589	1.622	1.656	1.693	1.734	1.781	1.842	1.985
0.46	1.930	1.446	1.475	1.504	1.535	1.567	1.602	1.639	1.680	1.727	1.788	1.930
0.47	1.878	1.394	1.422	1.452	1.483	1.515	1.549	1.586	1.627	1.675	1.736	1.878
0.48	1.828	1.343	1.372	1.402	1.432	1.465	1.499	1.536	1.577	1.625	1.685	1.828
0.49	1.779	1.295	1.323	1.353	1.384	1.416	1.450	1.487	1.528	1.576	1.637	1.779
0.50	1.732	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.590	1.732
0.51	1.687	1.202	1.231	1.261	1.291	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	1.643	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	1.600	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.458	1.600
0.54	1.559	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	1.518	1.034	1.063	1.092	1.123	1.156	1.190	1.227	1.268	1.315	1.376	1.518
0.56	1.479	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337	1.479
0.57	1.441	0.957	0.986	1.015	1.046	1.079	1.113	1.150	1.191	1.238	1.299	1.441
0.58	1.405	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262	1.405
0.59	1.368	0.884	0.913	0.942	0.973	1.006	1.040	1.077	1.118	1.165	1.226	1.368
0.60	1.333	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
0.61	1.299	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
0.62	1.265	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
0.63	1.233	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	1.201	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	1.169	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
0.66	1.138	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
0.67	1.108	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
0.68	1.078	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
0.69	1.049	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
0.70	1.020	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.71	0.992	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.964	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.936	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.74	0.909	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.882	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.855	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.829	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.802	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.776	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.80	0.750	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750

[11]

Reactive Power Calculation

Resonance Power Calculation

$$Q_{res} = \frac{S}{n^2.\%u_k.\sin\varphi_k}$$

S = Apparent Power of Transformer

n = Harmonic level ($3^{rd}, 5^{th}, 7^{th}, etc$)

$\%u_k$ = Short circuit voltage

φ_k = Short circuit voltage angle

COMPANSATION POWER must be
LESSER than
RESONANCE POWER

[10]

Reactive Power Compensation

Example

A single-phase ac voltage of 240V is applied to a series circuit whose impedance is $10\angle 60^0\,\Omega$. Find R,X,P,Q and power factor of the circuit.

Solution

$$Z = R + jX = 10\angle 60^0 = 10(\cos 60^0 + j\sin 60^0)$$
$$R = 10\cos 60^0 = 10(0.5)\Omega = 5\Omega$$
$$X = 10\sin 60^0 = 10(0.866)\Omega = 8.66\Omega$$
$$I = \frac{V}{Z} = \frac{240\angle 0^0}{10\angle 60^0} = 24\angle -60^0\,A$$
$$S = |I_{rms}|^2 Z = P + jQ$$
$$P = |I_{rms}|^2 R = |24|^2\,5 = 2880W$$
$$Q = |I_{rms}|^2 X = |24|^2\,8.66 = 4988VAR$$
$$powerfactor = \cos\left(\tan^{-1}\frac{X}{R}\right) = 0.50$$

Reactive Power Compensation

Example

If a capacitor is connected in parallel with the circuit of previous example and if this capacitor supplies 1250 VAR, find the P and Q supplied by the 240-V source and find the power factor.

Solution

$$P = |I_{rms}|^2 R = |24|^2\,5 = 280W$$
$$Q = Q_L - Q_C = 4988 - 1250 = 3738VAR$$
$$powerfactor = \cos\left(\tan^{-1}\frac{3738}{2880}\right) = 0.61$$

Reactive Power Compensation

Reactive Power Compensation

Before

Reactive Power Compensation

After

UTILIZATION OF ELECTRICAL ENERGY

Reactive Power Compensation

Before

Reactive Power Compensation

After

Reactive Power Compensation

REFERENCES

1. Bayındır, K.Ç. and Teke A., "EE 317 Utilization of Electrical Energy Course", Cukurova University Lecture Notes.
2. Sevailoğlu, O., "EE 209 Fundamentals of Electrical and Electronics Engineering Course", METU Three Phase Systems Lecture Notes.
3. C. L. Wadhwa, Generation, Distribution, and Utilization of Electrical Energy.
4. S.W. Fardo, D. R. Patrick, Electrical Power Systems Technology.
5. S.Sivanagaraju, M.Balasubba Reddy, D.Sirilatha, "Generation and Utilization of Electrical Energy"
6. Syed A. Nasar, Theory and Problems of Electric Power Systems.
7. James W. Nilsson and Riedel, Electric Circuits.
8. Charles Alexander, Matthew Sadiku, Fundamentals of Electric Circuit.
9. Various technical handbooks, industrial manuals, and web sites.
10. Aktif Mühendislik "Kompanzasyon Ürünleri ve Enerji Kalitesi"

UTILIZATION OF ELECTRICAL ENERGY

CONTACT INFORMATION

For your questions, please send the email to otimur@cu.edu.tr

As your instructor,
I ask you to pay attention some details particularly when asking your questions.

- **Please don't hesitate to ask your questions.**
- **Please don't ask questions not related to the lecture.**
- **Ask only the question part you do not understand, not the whole problem.**