Case Study On Power Factor Improvement

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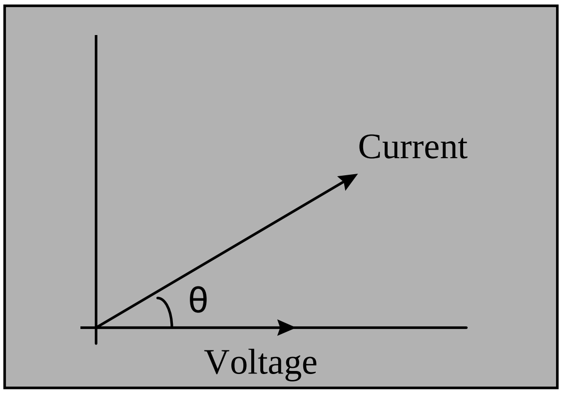
Abstract- Electrical Power constitutes a major component of the manufacturing cost in industry. In an electrical installation, power factor may become poor because of induction motors, welding machines, power transformers, voltage regulators, arc and induction furnaces, choke coils, neon signs etc. A poor power factor for the plant causes huge amount of losses, leading to thermal problem in switchgears. However power factor is controllable with a properly designed power factor improvement capacitors system. The power factor correction obtained by using capacitor banks to generate locally the reactive energy necessary for the transfer of electrical useful power, allows a better and more rational technical-economical management of the plants. This paper describes different aspects of power factor improvement in a typical industrial plant with the help of a case study.

Index Terms— Power factor, Capacitor, Nomogram, Reactive power

1. Introduction

Most of the electric energy used in world is generated, distributed and utilised in sinusoidal form. Sources of this type are frequently called alternating current (ac) source. The figure-1 shows the typical voltage and current vectors in an ac circuit. The angle θ between voltage and current is called power factor angle and the cosine of this angle is called the power factor. The cosine θ depicts that component of current which is in phase with voltage.



A typical vector diagram for ac voltage & current

Fig-1, Vector diagram for ac voltage & current

The resistive loads in an electric circuit has a power factor of unity,whereas for a purely inductive load the power factor is zero. However, in practice, the actual loads in an electric circuit are partly resistive and partly inductive. This combination of inductive and resistive loads makes the power factor of the plant to a value between zero and one. Lower the power factor, more are the losses, or in other words for an efficient operation of the plant, the power factor should be close to unity.

To improve the power factor, shunt capacitors are used. The value of capacitance required is a function of the type of electrical load in the plant. In view of the capital cost involved for installation of capacitors, a reasonably high power factor of the order of 0.8 to 0.9 is considered while designing the capacitors for power factor control.

2. Working Principle

Reactive power can be described as a by-product of electrical energy system. It circulates through the generators, transmission lines and transformers, but it is not delivered anywhere. It must be recognised and accounted for, however, since it plays an important role in the stability, cost of power and voltage control of the system.

Reactive power is measured much like active power, that is, through a vector product of current and voltage. Reactive power does not dissipate any energy other than the losses it creates through current circulation in the equipment and the transmission lines. Every kind of load except a perfect heating load generates reactive power.

Reactive power can be leading (current vector leading the voltage vector) or it can be lagging (current vector lagging the voltage vector). Since reactive power can be leading or lagging, the total balance must be zero. The leading power is because of capacitance in the power circuit. Similarly, the lagging power is because of inductance in the power circuit.

Motors, transformers in the industries are large source of lagging (inductive) power. In order to control excessive lagging (inductive) power, capacitors may have to be connected in the power circuit. Since capacitors are the source of leading power, they compensate the lagging power created by common equipment in the industries like motors and transformers.

Capacitors should be located as near to the load as possible. However, this is not practically possible because of the cost, availability of space and other environmental conditions. Capacitors can be located as in :

i. Individual Compensation

In such installations capacitors are installed parallel to the equipment and are controlled by a common switch. This is generally suited for high output induction motors, furnaces, transformers.

ii. Group compensation

This method resorts to compensation of the group of loads fed from the same bus bar. This is particularly useful when small loads are connected to a common bus bar.

iii. Central Compensation

This can apply to HT and/or LT capacitors. The output of capacitors has to be divided in a number of steps with auto / manual control depending upon the initial power factor of the load and its variation.

3. Installation Guidelines

capacitors for overhead distribution system can be pole-mounted in banks of 300 to 3600 kVAr at nearly any primary voltage up to 34.5 kV phase to phase. Pad mounted capacitor are used for underground distribution system in the same range of sizes and voltage ratings.

Common Capacitors Connections

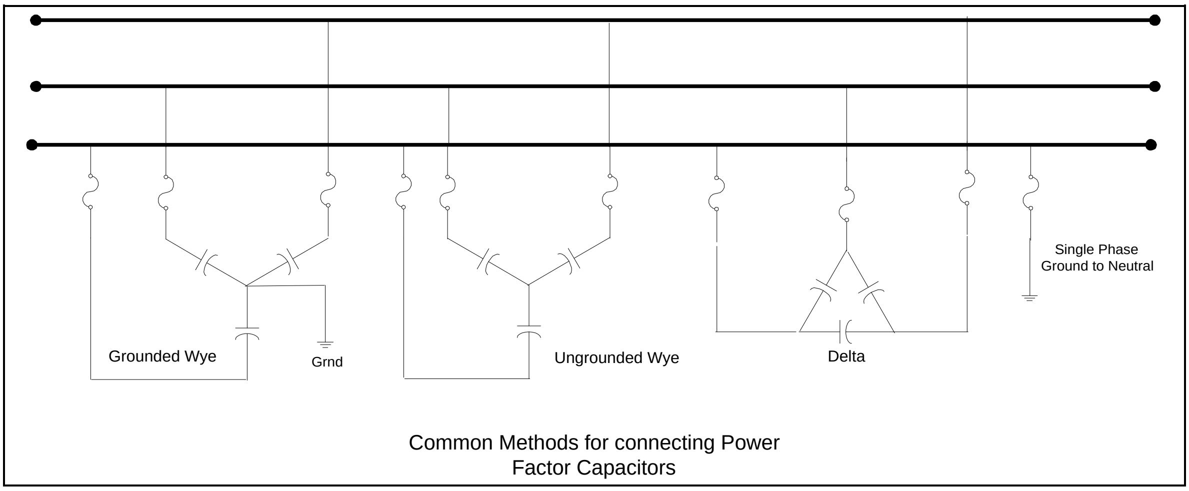


Fig-2, Common capacitor connections

The above figure-2 shows four of the most common capacitors connections : 3-phase grounded wye, 3-phase ungrounded wye, 3-phase delta and single phase. Grounded and ungrounded wye connections are usually made on primary circuits whereas delta and single phase connections are usually made on low voltage circuits.

The majority of the power capacitor requirement installed on primary distribution feeders is connected grounded wye. There are a number of advantages from this type of connection. With the grounded wye connection, switch tanks and frames are at ground potential. This provides increased personnel safety. Grounded wye connections provide faster operation of the series fuse in case of capacitor failure. Grounded capacitors can bypass some line surge to the ground and therefore exhibit a certain degree of self protection from transient voltages and lighting surges. The grounded wye connections also provide a low-impedance path for harmonics. If the capacitors are electrically connected ungrounded wye, the maximum full current would be limited to three times the line current. If too much fault current is available, generally above 5000 A, the use of current limiting fuses must be considered.

4. Estimation of KVAR required to improve power factor:

A quick estimate of capacitive KVAR required for improvement of power factor at a given load can be made from the Nomogram shown in the figure. However in most cases the capacitor bank rating has to be carefully selected after due consideration of rated voltage of the system, system over voltages, harmonics in the system, rating of series reactor etc. A Nomogram (fig-3) is used for calculating the necessary capacitor rating QC (kVAr) required to improve the power factor of a load P (KW) :

QC = K x P

Example :

for a load P of 1500 KW, to improve power factor from 0.6 to 0.85, the factor K from Nomogram is 1.4.

QC = 1.4 x 1500 = 2100 kVAr

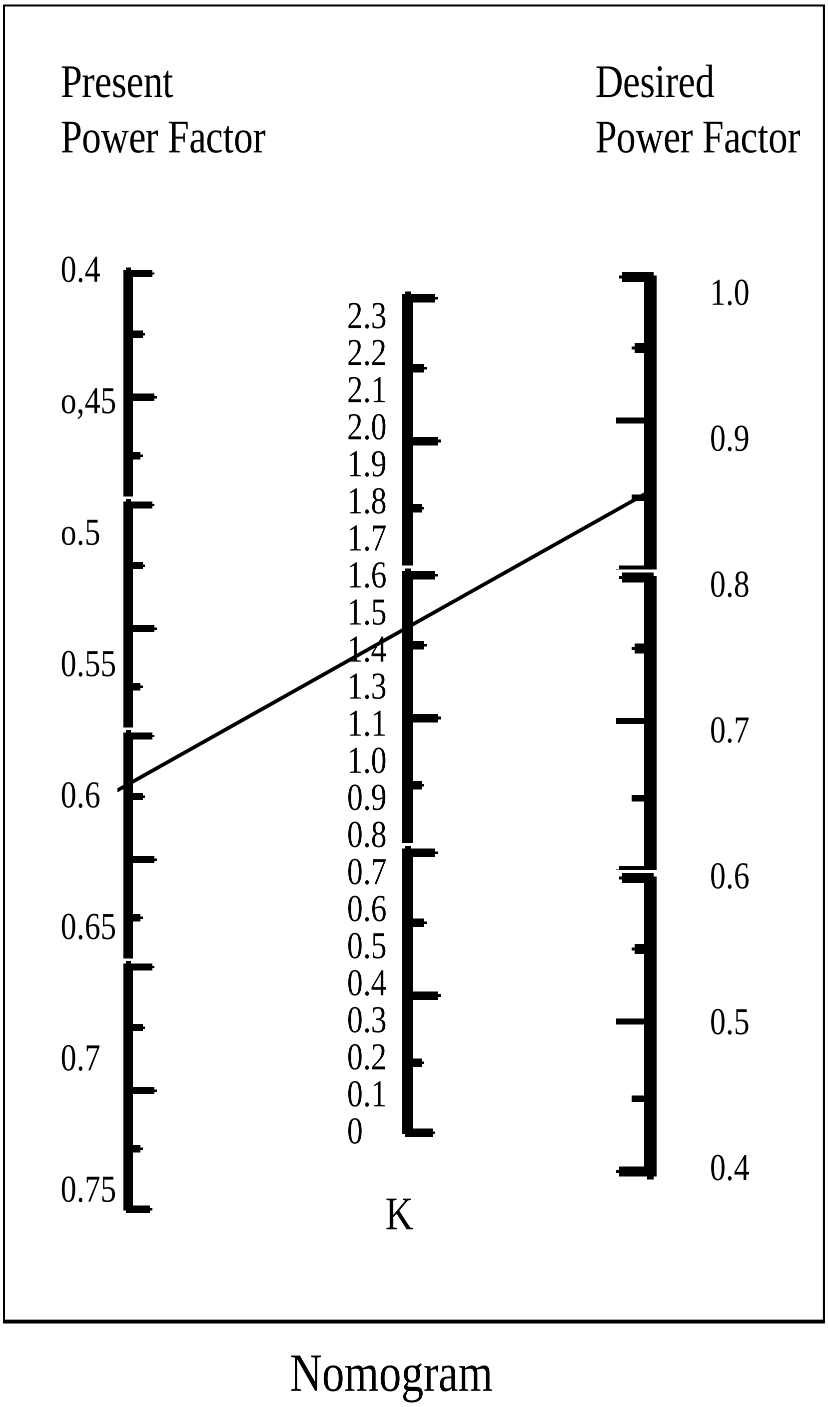


Fig-3,Nomogram

Case Study:

Here in this case study we are considering a industrial installation where there is one HT switchgear with two incomers and four LT switchgear with two incomers. We have calculated resistance of power cables and busbars which is required to calculate power loss in the existing power factor. We have taken desired power factor as 0.95 and again calculated the losses at new power factor. The difference between the two is 4.5 kilowatt per hour. In one year this gain will be 39420 kwhr . If we take Energy cost as Rs 6.5per kwhr, there will be saving of gain will be Rs 2.56 lakhs. In addition there will be considerable reduction in heating in these switchgears which will improve the reliability of the switchgear and the power system. Total reactive power required to improve power factor to 0.95 is 967 Kvar

	Parameters with Existing Power Factor						
	P.F.	kW	kVAR	kVA	I(LV)	I(HV)(line)	I(HV)(phase)
PMCC2							
IC1	0.784	342	270	437	607.975	38.22871	22.07200196
IC2	0.765	345	342	445	619.105	38.92855	22.47606607
PMCC3							
IC1	0.762	365	307	475	660.842	41.55294	23.99130648
IC2	0.852	367	223	432	601.018	37.79131	21.81946189
PMCC4							
IC1	0.909	98	45	109	151.646	9.535307	5.505373487
IC2	0.86	88	52	101	140.516	8.835468	5.101309378
PMCC5							
5E	0.874	930	518	1065	1481.68	93.16607	53.79103453
PMCC8							
IC1	0.8	40	30	49	68.1711	4.286514	2.474892668
IC2	0.67	37	39	55	76.5185	4.811393	2.77794075
Main IC1	0.686	1385	1476	2020	176.709	35.34187	20.40523751
Main IC2	0.85	4785	2975	5620	491.637	98.32738	56.77100733

Chart:-1 Parameters with existing Power Factor

Parameters with Desired Power Factor								
	P.F.	kW	kVAR	kVA	I(LV)	I(HV)	I(HV)(phase)	Required Reactive Power
PMCC2								
IC1	0.95	342	112.409964	360	500.8487	31.49276	18.1828849	157.590036
IC2	0.95	345	113.3960163	363.1578947	505.2421	31.76901	18.3423839	228.6039837
PMCC3								
IC1	0.95	365	119.9696984	384.2105263	534.5315	33.61069	19.4057105	187.0303016
IC2	0.95	367	120.6270666	386.3157895	537.4604	33.79486	19.5120432	102.3729334
PMCC4								
IC1	0.95	98	32.21104231	103.1578947	143.518	9.02424	5.21030035	12.78895769
IC2	0.95	88	28.92420126	92.63157895	128.8733	8.103399	4.67863705	23.07579874
PMCC5								
5E	0.95	930	305.6762178	978.9473684	1361.957	85.6382	49.444687	212.3237822
PMCC8								
IC1	0.95	40	13.14736421	42.10526316	58.57879	3.683363	2.12665321	16.85263579
IC2	0.95	37	12.16131189	38.94736842	54.18538	3.407111	1.96715422	26.83868811

Chart:-2 Parameters with Desired Power Factor

	Calculation for resistance										
	CABLE HV(185sq mm Al.)			**BUSBAR LV(Al. ρ=.03816(Ω sq.mm)/m at 20degC**				**TRANSFORMER RESISTANCE**		**NET RESISTANCE**	
	R(ohm/km)at 70degC	**CABLE LENGTH(meter)**	**RESISTANCE (ohm)**	**THICKNESS(mm)**	**WIDTH(mm)**	**LENGTH(meter)**	**RESISTANCE(ohm)**	**HV(ohm)**	**LV(ohm)**	**HV(ohm)**	**LV(ohm)**
PMCC2											
IC1	0.198	70	0.01386	10	150	7	0.00017808	0.257	0.000365	0.27086	0.00054308
IC2	0.198	75	0.01485	10	150	7	0.00017808	0.257	0.000365	0.27185	0.00054308
PMCC3											
IC1	0.198	65	0.01287	10	150	8	0.00020352	0.257	0.000365	0.26987	0.00056852
IC2	0.198	70	0.01386	10	150	8	0.00020352	0.257	0.000365	0.27086	0.00056852
PMCC4											
IC1	0.198	65	0.01287	10	150	7	0.00017808	0.257	0.000365	0.26987	0.00054308
IC2	0.198	60	0.01188	10	150	7	0.00017808	0.257	0.000365	0.26888	0.00054308
PMCC5											
5E	0.198	70	0.01386	10	150	7	0.00017808	0.257	0.000365	0.27086	0.00054308
PMCC8											
IC1	0.198	280	0.05544	10	150	6	0.00015264	0.257	0.000365	0.31244	0.00051764
IC2	0.198	275	0.05445	10	150	6	0.00015264	0.257	0.000365	0.31145	0.00051764
	CABLE HV(630sq mm Al.)										
HT											
IC1	0.0582	1500	0.0873	10	160	7	0.00016695	0.318	0.003505	0.4053	0.00367195
IC2	0.0582	1500	0.0873	10	160	7	0.00016695	0.318	0.003505	0.4053	0.00367195

Chart-3: Calculation of resistance

				Loss Calculation before pf correction					
	NET RESISTANCE			CURRENT(before)			LOSSES(before)		Total Losses(before)
	HVt/f(ohm)	HVline(ohm)	LV(ohm)	HVline(amp)	HVphase(amp)	LV(amp)	HV(watts)	LV(watts)	(watts)
PMCC2									
IC1	0.257	0.01386	0.00054	38.2287074	22.07200196	607.97462	436.377	602.2211	1038.598122
IC2	0.257	0.01485	0.00054	38.92854643	22.47606607	619.10459	457.0013	624.4722	1081.473499
PMCC3								0	
IC1	0.257	0.01287	0.00057	41.55294282	23.99130648	660.84198	510.4402	744.8387	1255.278904
IC2	0.257	0.01386	0.00057	37.791308	21.81946189	601.01839	426.4484	616.0877	1042.536087
PMCC4								0	
IC1	0.257	0.01287	0.00054	9.535306879	5.505373487	151.64584	26.87885	37.46676	64.34560213
IC2	0.257	0.01188	0.00054	8.835467842	5.101309378	140.51587	22.84626	32.16887	55.01513542
PMCC5								0	
5E	0.257	0.01386	0.00054	93.1660718	53.79103453	1481.6773	2591.78	3576.781	6168.561154
PMCC8								0	
IC1	0.257	0.05544	0.00052	4.286514102	2.474892668	68.171068	7.778445	7.216877	14.99532124
IC2	0.257	0.05445	0.00052	4.81139338	2.77794075	76.518545	9.731244	9.092483	18.82372692
HT								0	
IC1	0.318	0.0873	0.00367	35.34187137	20.40523751	176.70936	724.3462	343.9831	1068.329265
IC2	0.318	0.0873	0.00367	98.3273847	56.77100733	491.63692	5606.813	2662.607	8269.419376
						Total Losses =			**20077.37619**

Chart-4: Loss calculation at existing power factor

			Loss Calculation after pf correction						
	NET RESISTANCE			CURRENT(after)			LOSSES(after)		Total Losses(after)
	HVt/f(ohm)	HVline(ohm)	LV(ohm)	HVline(amp)	HVphase(amp)	LV(amp)	HV(watts)	LV(watts)	(watts)
PMCC2									
IC1	0.257	0.01386	0.000543	31.4927567	18.18288491	500.8487	296.1447	408.6938	704.8385687
IC2	0.257	0.01485	0.000543	31.7690089	18.3423839	505.2421	304.3606	415.8954	720.2559244
PMCC3								0	
IC1	0.257	0.01287	0.000569	33.6106906	19.4057105	534.5315	333.9613	487.3192	821.2805341
IC2	0.257	0.01386	0.000569	33.7948588	19.51204316	537.4604	341.0232	492.6743	833.6975418
PMCC4								0	
IC1	0.257	0.01287	0.000543	9.02424021	5.210300355	143.518	24.07479	33.55815	57.63294526
IC2	0.257	0.01188	0.000543	8.10339938	4.678637053	128.8733	19.21722	27.05897	46.27618754
PMCC5								0	
5E	0.257	0.01386	0.000543	85.638198	49.44468704	1361.957	2189.867	3022.121	5211.987262
PMCC8								0	
IC1	0.257	0.05544	0.000518	3.68336335	2.126653206	58.57879	5.743457	5.328806	11.07226282
IC2	0.257	0.05445	0.000518	3.4071111	1.967154216	54.18538	4.879769	4.559459	9.439227911
HT								0	
IC1	0.318	0.0873	0.003672	25.5072912	14.72707345	127.5365	377.3078	179.1788	556.4866145
IC2	0.318	0.0873	0.003672	88.1244682	50.88017795	440.6223	4503.603	2138.706	6642.308767
						Total Losses			**15615.27584**

Chart-5: Loss calculation after improved power factor.

It is evident from the above charts that power factor of PMCC-8 , I/C-2 and main I/C-2 are very low in comparison to other switchgears. Immediate steps are to be taken to improve the power factor of both the switchgears. KVAR required to design the capacitor bank can be taken from chart-2 or using Nomogram as discussed in the chapter-4 of this paper.

5. Conclusion

The low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all the elements of power system from power station generator down to utilisation devices. In order to ensure most favourable conditions for a supply system from engineering and economical standpoint, it is important to have power factor as close to unity as possible.

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