Reactive Power Compensation Using Fuzzy Controller

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Summary
The nature of load whether industrial or residential is more or less inductive rather than resistive. Therefore always the power factor remains to be as low as cos $90^0 = 0$. Such a condition of p.f. is highly disadvantageous to the supplier and due to this reason the supplier fixes the tariff, at certain fixed value of power factor which may be 0.8 and above. The concept of power factor improvement is same as reactive power compensation. The consumer has therefore to maintain a bank of capacitors with in his premises. These capacitors are to be put across the load to preserve the power factor at some threshold value. Also beyond certain level the approach of P.F. improvement or reactive power compensation proves to be uneconomical because the cost of capacitor outweighs the profits of savings caused by the addition of extra capacitance at the load end. The efforts have been made in the present work to develop a fuzzy controller to enable the capacitance of right size to be added across the load so that the cost of operation is minimum or the saving is maximum. Based on the out come of fuzzy controller the actual feed back control system would enable the right size of capacitance to be placed across load. The automation in p.f. Control would always ensure that the size of capacitance to be placed across the load is responsive to the desired improvement in p.f. or reactive power compensation.

Key words:
Power Factor, Power demand, Fuzzy Rule, Inductive load, Fuzzy controller, System frequency, Gaussian distribution.

1. Introduction

The improvement in power factor is caused by placing extra capacitor across the load. The improvement in power factor leads to many advantages such as release of extra capacity in the same system of power flow to handle more power flow. It helps in reducing both fixed and running costs of any power system. It however incurs the cost of capacitor, which is placed across the load. The increase in size of capacitor, which shunts the load, leads to more saving in fixed & running cost but the cost of capacitor becomes prohibitive. The present work aims at estimating the optimal size of capacitor, which leads to maximum net saving. The problem has been tried both deterministically and by way of fuzzy rule based control of p.f. Improvement / reactive power compensation reactive power demand of the load locally and spares the source from feeding the same and therefore amounts to release extra capacity from the same source. As such it is aimed to obtain the optimal size of capacitor, which leads to most economical power factor/optimal compensation of reactive power. Any departure in size of capacitor from the optimal one leads to reduced saving. If μ is the degree of compensation

Then,

$$\mu = \frac{Q_c}{Q}$$

Where

Q_c = Compensated reactive power demand by the Capacitor bank

Q = Reactive power demand of the load.

Consider a radial feeder supplied by a Generator. As shown in fig (1)

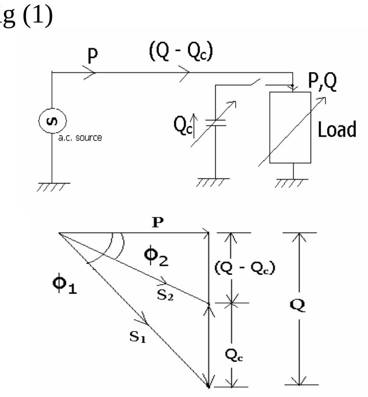


Fig. 1: Illustration of power factor improvement

The power factor before insertion of capacitance 'C' is

$$\cos\phi_1 = \frac{P}{S_1} = \frac{P}{\sqrt{P^2 + Q^2}}$$

The power factor after insertion of capacitance 'C' is

Manuscript received June 5, 2008.
Manuscript revised June 20, 2008.

$$\cos\phi_2 = \frac{P}{S_2} = \frac{1}{\sqrt{P^2 + (Q - Q_c)^2}}$$

Since, the capacitance cannot be raised after the threshold value, is leads to value of p.f, p.f angle ϕ_2, compensated reactive power (Q_c), reduced VA demand from the source and the degree of compensation μ to have the threshold value.i.e. $(p.f)_{th}$, $(\phi_2)_{th}$, $(Q_c)_{th}$, $(S_2)_{th}$, μ_{th}.Thus every new demand of active power at the load end, will require an optimal degree of reactive power compensation μ_{th} through optimal size of capacitor C_{th}. This enables the net saving to maximize under variable condition of power demand at load end. As a result all the time the operation of any power system would remain to be most economical. The problem has also been solved using fuzzy rule based control of improvement in power factor / reactive power compensation. The results with fuzzy control has been encouraging because these are obtained without the mathematical modeling.

2. Deterministic Approach

For a given active power demand P, there exists and optimal degree of reactive power compensation $(\mu)_{Th}$ / optimal p.f. improvement $(Cos\phi_2)_{Th}$ and therefore are optimal value of capacitor C_{Th}

The net saving due to application of shunt capacitor

$$S_{net} = \text{Profit-}C_c$$

$$\text{Profit} = \left(C_{equip+losses}\right)_{withoutC} - \left(C_{equip+losses}\right)_{withC} - C_c$$

= Cost of capacitor

for maximum value of S_{net}

$$\frac{ds_{net}}{d\mu} = 0$$

Which gives the Threshold value of $(\mu)_{th}$ i.e,

$$(\mu)_{th} = 1 - \frac{1}{X \tan\phi_1}$$

where,

$$X = \left[\left(C_F + C_R \cdot \frac{P}{V^2 Cos\phi_1}\right)^2 - 1\right]^{1/2}$$

$$C_F = \frac{C_{eqip}}{C_r}$$

$$C_R = 2.\frac{C_{Losses}.R_{Path}}{C_r}$$

It gives,

$$(Q_c)_{Th} = (\mu)_{Th}.Q$$

$$Q = S.\sin\phi_1$$

and

$$C_{Th} = \frac{(Q_c)_{Th}}{2\pi fV^2}$$

Where

C_F = Fixed cost of the system

C_R = Running cost of the system

C_{Losses} = Cost of losses per Kw basis

R_{Path} = $R_G + R_T + R_{Line}$

C_{eqip} = cost of equipments per KVA basis

C_r = cost of reactive power compensation per KVAR basis

P = power demand at time t.

Q = Reactive power demand at time t.

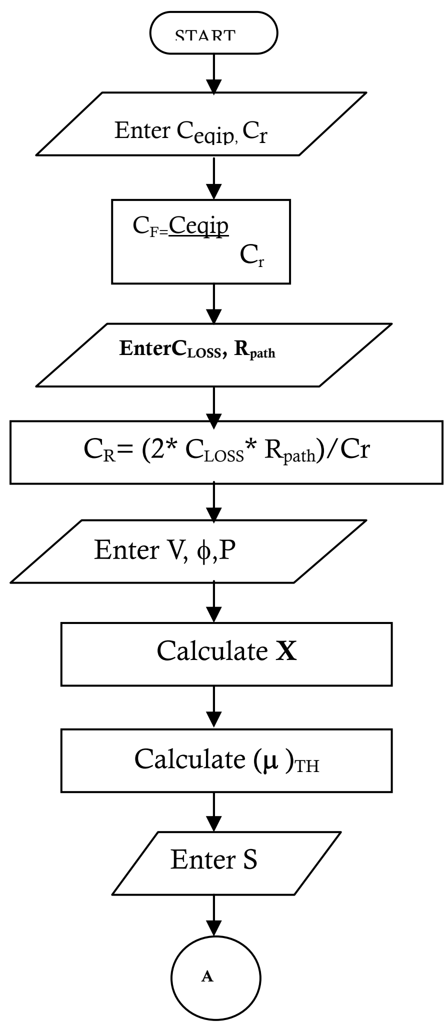
S = Source VA.

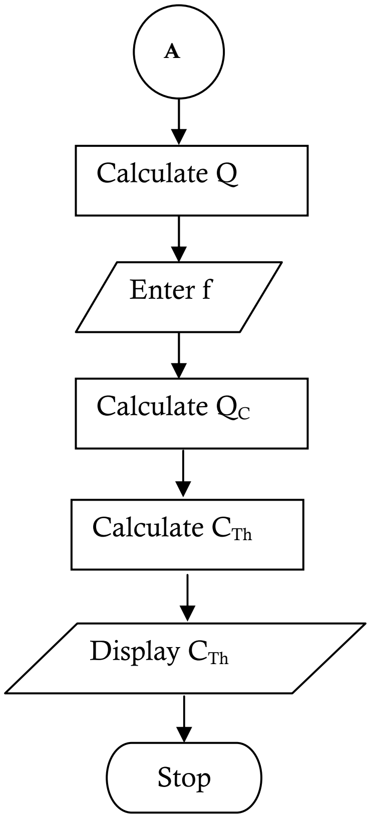
V = System voltage.

f = System frequency.

ϕ_1 = Power factor angle at time t.

3. Flow Chart



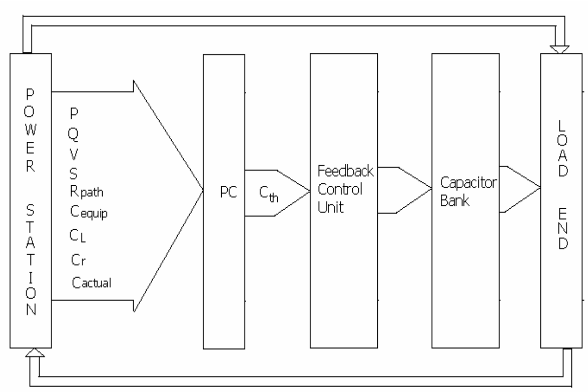



```
#include<stdio.h>
#include<conio.h>
#include<math.h>
main()
{
float x,p,q,v,f,s,rp,Ce,Cl,CF,CR,Cr,,phi1, ,Cth,qc;
float i,j,k,m,a;
printf("enter the value of Ce,Cr");
scanf("%f%f",&Ce,&Cr);
CF=Ce/Cr;
printf("¥n%f",CF);
printf("¥n enter Cl, rp");
scanf("%f%f",&Cl,&rp);
CR=(2*Cl*rp)/Cr;
printf("¥n%f",CR);
printf("¥nEnter V ,phi1,p");
scanf("%f%f%f",&v,&phi1,&p);
i=CF+(CR*p)/v*v*cos((3.14*phi1)/180);
j=(i*i)-1;
x=sqrt(j);
printf("¥n%f",x);
m=1-(1/x*tan((3.14*phi1)/180));
printf("¥n%f",m);
printf("¥n enter s");
scanf("%f",&s);
q=s*sin((3.14*phi1)/180);
printf("¥n%f",q);
qc=m*q;
printf("¥n%f",qc);

printf("¥n enter f");
scanf("%f",&f);
Cth=qc/(2*3.14*f*v*v);
printf("¥n Cth=%f",Cth);
getch();
}
```

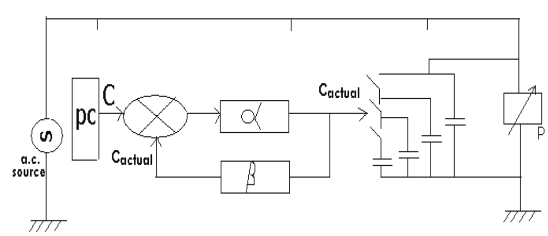
Table 1: Results for different ‘P’

Power (P)KW	Capacitor (C)µ Farad
25	0.062
40	0.08
50	0.093
70	0.11
80	0.14
85	0.152



Block diagram

Fig.2: Adaptive control of optimal power factor improvement for varying Load using PC



Line Diagram

Fig.3: Adaptive control of optimal power factor improvement for varying Load using PC

Fig (2) & (3) Shows the Bock diagram and line diagram of Adaptive control of optimal power factor improvement for varying Load using PC

4. Fuzzy Approach

The present system works on the principles of crisp value where mathematical modeling is used to obtain the result. Since the actual system are operated on knowledge base, which is better, expressed by the linguistic rules. By using the linguistic rules it is possible to control the improvement in power factor by fuzzy decision controller. This approved is more realistic and reliable as it is a kind of model free approximation for this purpose the range in which the active power demand (P) varies and the range in which the (p.f) variation takes place are taken as input shown in fig. (4) which provides the value of 'C' which gives best economy after the improvement in p.f is effected. The fuzzy rule base has been given in Table (2)

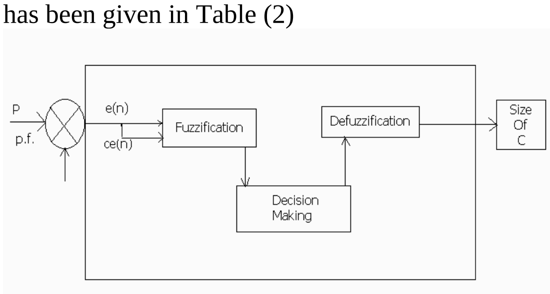


Fig. 4: Fuzzy Decision Controller

Each fuzzy rule is basically a function of If and THEN rule statement e.g. value of C which yields the required improvement is p.f. is obtained after due defuzzification.
The above fuzzy decion control has been proposed for the desired control of improvement in (p.f). The inputs to the fuzzy controller are active power demand (P) & the p.f. , Where as the output of the controller is size of 'C'. The P various between 0-100 Kw. P.f. varies between 0.25 –1 & the size of capacitor varies between 0.06μF to 0.16 μF. The fuzzy decision controller uses 25 rules to yield the value of C for given P and p.f.
The control action of the fuzzy decision controller is as shown.

Table 2: Fuzzy rules

power

pf	**VL**	**L**	**M**	**H**	**VH**
VL	VH	H	M	L	VL
L	H	M	L	VL	VL
M	M	L	L	VL	VL
H	L	VL	VL	VL	VL
VH	VL	VL	VL	VL	VL

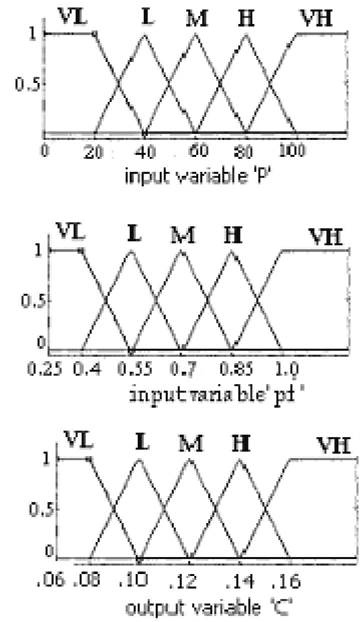


Fig 5:Universe of discourse of variables P, pf &C

4. Conclusion

The active power demand & the P.F. of any load is decided by the customer's need. The reactive power demand of an inductive load can be supplied at the load end by inserting shunt capacitor across the load. Defuzzifying the fuzzy sets power & power factor yields the size of capacitor to be inserted across the load for improving the power factor. These results are closer & better than those obtained by deterministic approach. This is because the fuzzy controller is basically a model free approximater & works on linguistic rules, rather than rigid mathematical formulas. Further it is possible to achieve automation in power factor or reactive power compensation improvement using the fuzzy rules as proposed.

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