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Soft Power Factor Modification Using Static VAR Compensator on Dynamic Load

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Energy Field of Study

Abstract: **A good power quality at a system can optimize the efficiency of electrical energy utilization. Comparison of active power and apparent power will produce a power factor (COS ø).Capacitors bank can maintain optimum power factor with compensating some reactive power to the system. Static VAR Compensator (SVC) is generally composed of a conventional capacitor bank in parallel with the load contactor switch. This leads to a very large inrush current to the capacitor which will resulting damage to the contactor switches and also capacitors. To reduce inrush current, thyristor is used as a replacement of contactor switch. Switch can be set by adjusting the firing angle of thyristor. Power factor improvement consists of a voltage sensor, current sensor, zero crossing detector, thyristor driver and the capacitor bank. The existing load on the system consists of induction motor 125W, rectifier with load of series of incandescent lamp with ballasts 85W and fluorescent lamp 20W.Cos phi variation of the load is 0.49 (lag), 0.99 (lag), 0.92 (lag) and 0.62 (lag) when all the loads connect to the system. Through the calculation, the value of capacitor that can compensate the reactive power to the system is 5.12 μF, 2.71 μF, 2.41 μF and 9.55μF. The capacitor installation obtain good response because it can increase the cos phi of system to 0.99 (lag) and the current consumption of the system is smaller than the pre-installation of capacitors, which can reduce the line system current up to 30% of the system current.**

Keywords: **Power quality, Power factor, Inrush current, Soft switches.**

I. INTRODUCTION

Good power quality in a system can optimize the maximum power demand and efficiency of utilization of electrical energy. One way to do is to use capacitor banks to maintain the power factor. Types of loads that affect the quality of electric power is inductive loads and non-linear loads such as converters and inverters for motor drives , welding machines , arc furnaces , computers, air conditioners , TVs , fluorescent lamp and others. The use of non- linear inductive load and power factor is exacerbating thereby increasing the power loss. Disturbance in the form of voltage unbalance is caused by unbalanced load distribution.

Therefore, to maintain good power quality Static VAR Compensator necessary equipment (SVC) is used to compensate reactive power. Conventional SVC generally consists of a bank of capacitors connected in parallel to the load through an electromechanical switch contactor switch (EMS) . This leads to a very large inrush current to the capacitor itself. This happened repeatedly and will cause damage to the contactor switches and capacitors

II. METHOD

Work steps of the implementation of this final project are as follows:

2.1. Literature Study

Study the literature on the concept of power quality, switching solid state relay (SSR), power electronics and other material relevant to the discussion of this final project.

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2.2. Simulation System

At the end of the project, using as a media PSIM simulation program.

2.3. System Design

At the end of the project will be improved using a soft switch power factor at SVC for dynamic loads. Block diagram of the whole system is:

2.4 Integration and Testing System

To find out all the systems that have been designed in accordance with the expected result of integration of each device

III. BASIC THEORY

3.1. Use of Power Triangle and Table Cos φ Power factor improvement for Analysis

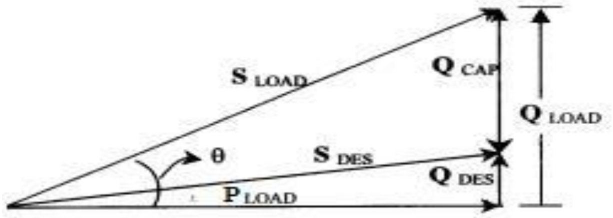

Figure 1: Power triangle

The sum of active power and reactive power generating real power

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

Where: P = active power (kW)

S = apparent power (KVA)

Q = reactive power (KVAR)

Power factor:
P = VI COS φ

(Active Power) / (Power Pseudo) = P / S = COS φ

Reactive power compensator:

Description:

P: Power on (watts)

Q: Compensator Reactive Power (VAR)

θ: Angle before repaired

φ: Angle after being repaired

Inrush Current

Inrush current is instantaneous inrush current with a value several times the normal flow arising on the electrical equipment at the beginning connected with a voltage source. This flow can occur in electrical equipment, among others, the incandescent light bulb, AC electric motors, power converters and transformers. In rush, current wave is similar to a sinusoidal wave but not symmetrical. Here is an example of inrush current curve:

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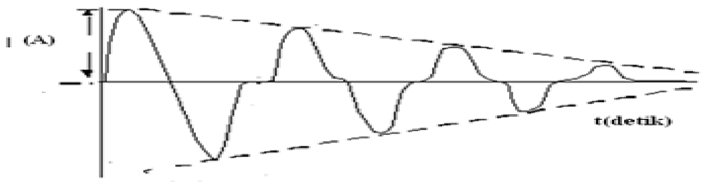

Figure 2: Flow curves Inrush

In a capacitor bank switching , inrush current formulation obtained as follows :

$\hat{i} = (\sqrt{2} \times Un) / \sqrt{(X_C \times X_L)}$

Where : $\hat{i}$: Inrush currents (Inrush current)

Un : Voltage Line – line

XC : reactance capacitive

XL : inductive reactance

Inrush current at switching on the capacitor can reach 20 times the normal current rating of the capacitor . This happens because at the time of the switching frequency over a very large capacitor banks that capacitive reactance becomes very small, according to the following formula:

$X_C = 1 / (2 \times \pi \times f \times C)$

Thus the current through the capacitor bank will be very large .Planning System

The design of the overall system can be described as the block diagram below:

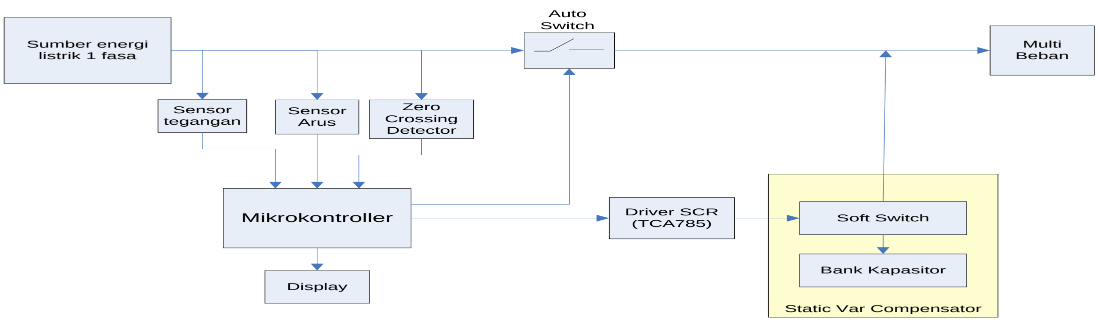

Figure 3: System Design

Table 1. Data for Simulation

1-Phase Induction Motor	
V	220 V
I	1.1 A
PF	0.26 Lag
θ	$74{,}93^0$
Rectifier	
load	Incandescent lamps of 100 W Ballast 40 W, PF = 0.54
TL lamps	
P	40 Watt fluorescent lamp

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1. Planning a soft switch with SCR

Soft switches using SCR fueled by the microcontroller to improve the power factor and eliminate inrush currents.

The means used to eliminate inrush current when the SCR is lit at the time of peak voltage (dv / dt = 0).

SCR = 0 voltage (Vth = 0), is reached when:

Vth = Vs - Vc as Vc = - Vm

Vth = Vm Sin ωt + Vm

= Vm (1 + Sin ωt)

Thus, Sin ωt = -1 ◊ ωt = Sin-1 (-1)

= 270o

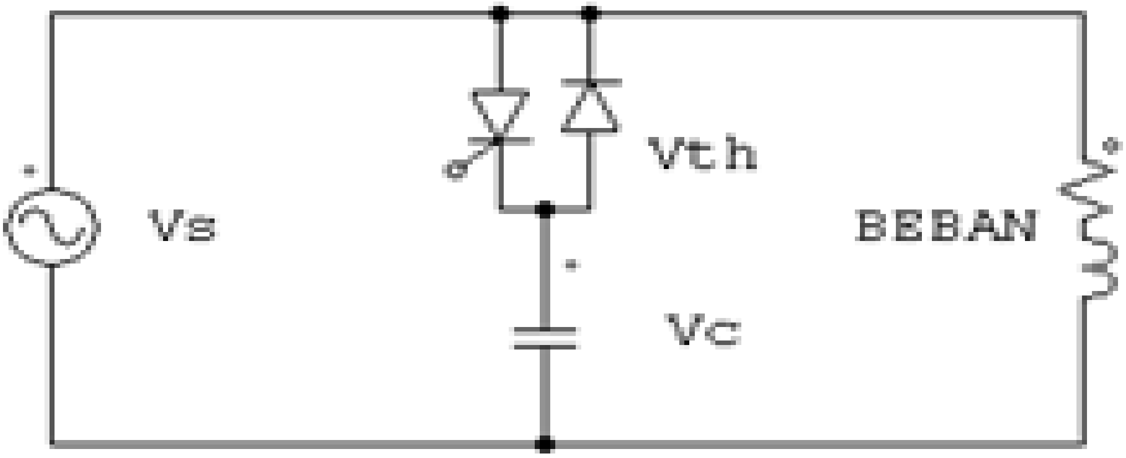

Figure 4: Soft Switch circuit SCR

Calculation of capacitor banks needed the motor load can be determined via equation 3.9, 3:10 equations and equation 3.11. To calculate the value of the capacitor bank must be specified PF value of the target, thus it can be seen that the value of the capacitor banks as required. If the supply of reactive power of the capacitor bank is too large it will result in cos θ is negative and the current signal will precede the voltage signal. If the supply of reactive power of the capacitor bank is too small then it will lead to improvement of the power factor is not maximal.

From the simulation results, it can be sorted lowest that real power is 1 only when the load is located on the system, and the highest is when the second load is on the system with the value of each parameter listed in the following table.

Table 2. Simulation Results before Installation of Capacitors

No	load	V	P	I	cos phi	remark
1	TL lamps	220	35	0.29	0.922	lag
2	Rectifier with load Lamp + Ballast	220	130	1.22	0.49	lag
3	Induction motors	220	85	0.39	0.99	lag
4	combination	220	236	1.72	0.62	lag

Further more, the calculation of the value of the capacitor to achieve Cos θ = 1 is as follows:

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PF target = 1 → $\theta_2 = 0^0$

$$Q_{cap} = P\,(tan\,\theta_1 - tan\,\theta_2)\,, \qquad C_{step} = \frac{Q_{cap}}{V_{ll}{}^2 .\, w}$$

1. Reactive power to be injected into the system

$$Q_{ca-load1} = P\,(tan\,\theta_1 - tan\,\theta_2)$$

$$= 63{,}57\,.(tan\,70{,}73^0 - tan\,0^0)$$

$$= 181{,}833\,VAR$$

$$Q_{cap-load2} = P\,(tan\,\theta_1 - tan\,\theta_2)$$

$$= 80{,}32\,.(tan\,24{,}495^0 - tan\,0^0)$$

$$= 36{,}596\,VAR$$

$$Q_{cap-load3} = P\,(tan\,\theta_1 - tan\,\theta_2)$$

$$= 143{,}095\,.(tan\,57{,}32^0 - tan\,0^0)$$

$$= 223{,}065\,VAR$$

From the results of these calculations, it can be sorted that reactive power to be injected is lowest when the load 2 are located on the system, and the highest is when the second load is on the system.

Determination of capacitor step will be installed, will be adapted to the conditions in which was done by determining the lowest Q, and then determined the difference between each value of Q to Q supreme. When the Load 2 are working, then the required reactive power requirement is 36.596 VAR then step 1 capacitor bank is worth as needed.

Furthermore, when the Load 1 only the work, it would require additional reactive power to be injected at 145.237 VAR, so step 1 and 2 lit. And when the second load of work together, it is necessary to return additional reactive power at 41.232 VAR, under these conditions, the third step should be lit to meet the target CO phi.

2. Capacitor value

$$C_{step\ 1} = \frac{Q_{cap}}{V_{ll}{}^2 .\ w} = \frac{36{,}596}{220^2 .\ 2 .\pi .50}$$

$$= 2{,}41\ \mu F$$

$$C_{step\ 2} = \frac{Q_{cap}}{V_{ll}{}^2 .\ w} = \frac{145{,}237}{220^2 .\ 2 .\pi .50}$$

$$= 9{,}55\ \mu F$$

$$3.\ C_{step\ 3} = \frac{Q_{cap}}{V_{ll}{}^2 .\ w} = \frac{41{,}232}{220^2 .\ 2 .\pi .50}$$

$$= 2{,}71\ \mu F$$

IV. TESTING SYSTEM

System testing performed in this study based on the design that has been made.

4.1. Voltage sensor

The results of the sensor voltage using a voltage divider circuit in line with expectations. The result of the voltage sensor is used to detect the phase difference at the zero crossing circuit.

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Table 3. Voltage sensor test data

No.	Arus AC [A_{ac}]	$V_{out\text{-}AC}$ (mV)	$V_{out\text{-}rec}$ (V)
1	0.75	93	1.87
2	1	114	1.89
3	1.25	135	1.914
4	1.5	160	1.94
5	1.75	175	1.97
6	2	206	1.99
7	2.5	257	2.04
8	3	295	2.09
9	3.5	342	2.14
10	4	390	2.195
11	4.5	440	2.25
12	5	488	2.32

From the table it can be seen that the output voltage of the sensor output either AC or DC voltage output theory approach.

4.2. ACS current sensor 712

Of ACS application circuit IC 712, the result output of AC voltage without a DC component. The resulting output signal IC ACS 712 is an inverting of the input signal. So, we need inverting amplifier output signal that is equal to the input signal IC ACS 712.

ACS trial data table:

Table 4. ACS current sensor experimental data 712

No.	**V input-ac**	**Vout-ac [V]**		**Vout-rec [V]**		**% Error**
		practice	**Theory**	practice	Theory	**Vout-rec**
1	100 V	1.566	1.363	1.305	1.23	6.1
2	120 V	1.806	1.629	1.576	1.47	7.2
3	140 V	2.18	1.909	1.827	1.72	6.2
4	160 V	2.498	2.181	2.025	1.96	3.3
5	180 V	2.806	2.454	2.315	[1] 2.21	4.7
6	200 V	3.12	2.727	2.486	2.46	1.1
7	220 V	3.42	3	2.88	2.7	1.6

Because, the output voltage signal of the IC 712 ACS is inverting the circuit using inverting amplifier with a gain of 20 times. So in the calculation of Rf and Ri as follows:

.... $V_{out} = \left(\frac{R_f}{R_i}\right) \times V_{in}$................(3.5)

If the gain 20 times, then

I

$$\frac{V_{out}}{V_{in}} = 20$$

Thus, form the equation 3.5:

$$\frac{R_f}{R_i} = \frac{Vout}{Vin}$$

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$$\frac{R_f}{R_i} = 20$$

$R_f = 20$ Ri
First set R1=1kΩ, then:

$$R_f = 20 \times 1000\Omega$$
$$R_f = 20K\Omega$$

A variable resistor is Rf. The value used is 20K Ω order to produce a gain of 20 times.

4.3. The circuit Zero Crossing and Phase Detector (Detector phase)

The circuit zero crossing detector and a continuation phase current sensors and voltage sensors . The resulting sensor output signal voltage and current sensors, and then processed by the zero crossing circuit and generates 2 -step signal which has a phase difference equal to the ac voltage and current signals. Then processed by the IC - XOR and generate signals that inform the data step phase difference between voltage and current .IC - XOR 2 is used as the summing of the input signal that is current and voltage signals that are output from the zero crossing that has a different phase, with the work as follows:

1. If both inputs same logic would then output is logic "0"

2. If both logic inputs are not equal then the output would be worth a logic " 1 " .Square wave signal coming out of the current and voltage zero crossing comparator circuit to get into compared to using IC 74LS86 TTL XOR to know the difference between the phase angle of the voltage and current flowing in the load.

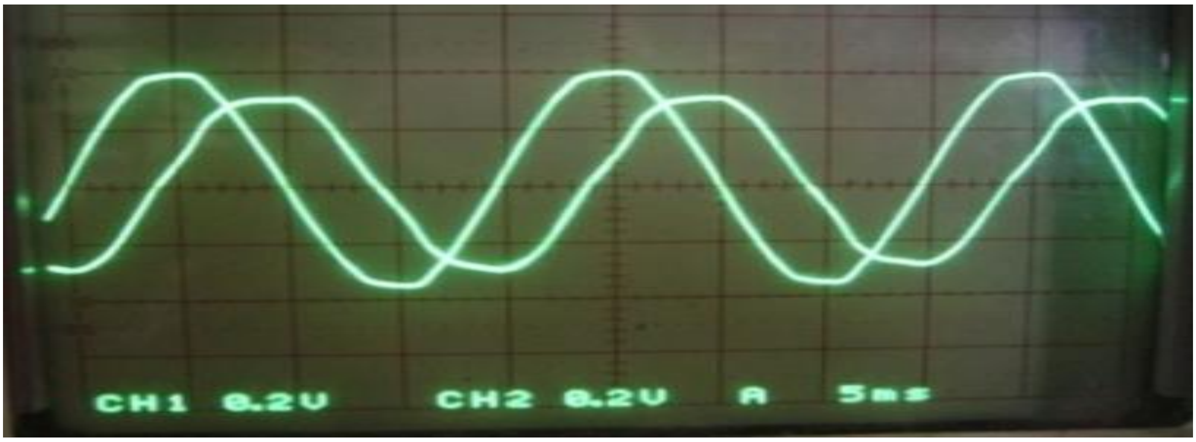

Figure 5: wave voltage sensor and current sensor

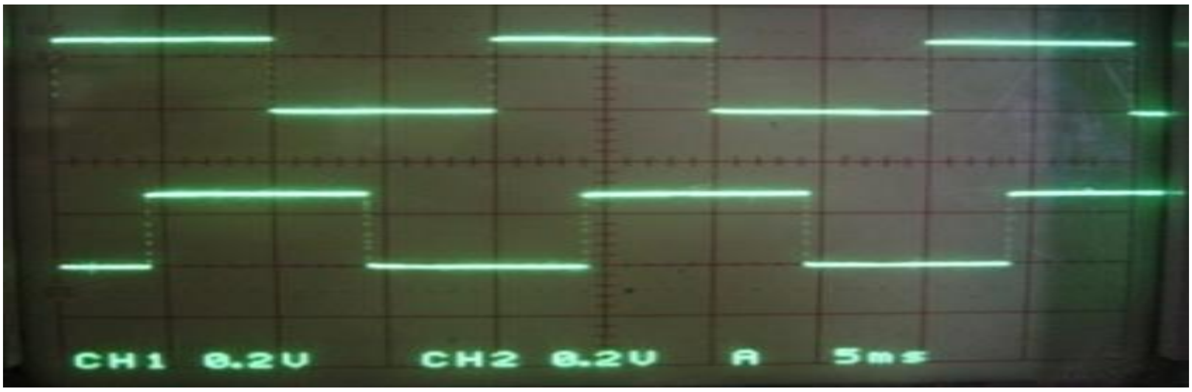

Figure 6: Wave output voltage divider voltage sensor and current sensor

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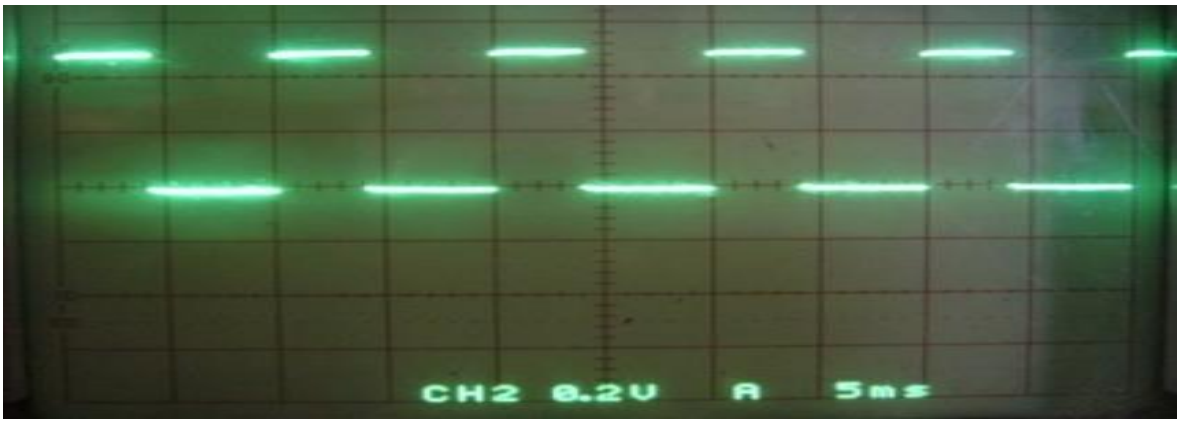

Figure 7: wave output of the EX-OR 74hc86 (phase detector parameters)

4.4. Testing System

To test the results of this system, obtained the following results:

Tabel 5. Validation System Without Capacitor With Meter

No	load	V	P	I	cos phi	% Error Vout-rec
1	TL lamps	220	35	0.29	0.922	2%
2	Rectifier with load Lamp + Ballast	220	130	1.22	0.49	2.1%
3	Pump motors	220	85	0.39	0.99	1.2%
4	All expenses 1,2,3	220	236	1.72	0.62	11.2%

In table 5 of the test system without capacitor can be seen that for COS phi reading on LCD graphics readout COS phi compared with analog meter has a high % error. On the third reading of the COS phi currently installed load is by 11.29 % when all load is attached. While at C0S phi readings on the percent error % lower reaches 1:01 .Error reading on the LCD due to the number of works on frequency control circuit and is also caused due to poor materials /components used in the circuit. Here are the results of testing the system before and after installation of capacitor banks, which, seen an increase in the value of the COS phi to 0.49 lag to 0.99 lag pump motor after installation of 5.12 **μ**F capacitor.

Similarly, when the three loads connected directly together, which are the initial COS phi 0.62 to 0.99 lag increases with the addition of the 9:55 **μ**F. In terms of the current line in the system, there is a reduction in current consumption due to the injection line from the capacitor bank reactive VAR. Seemingly that be saran a flow when the pump motor is initially to 0.82 A 1:22 A similarly when the combined load of 1.72 A to 0.94 A. rectifier load current on the line is not too powerful due COS phi initial value system that has both is 0.99 and 0.92 for fluorescent lamp load.

Table 6. System Testing Results before and after the installation of capacitor bank

No	Load	V (V)	I (A)	Cos phi	P(Watt)	S(VA)	C(F)
1	Pump Motor	=222	1.22	0.49 lag	135	271	5,12
		220	0.82	0.99 lag	179		
2	TL Lamp	222	0.29	0.92 lag	35	62	2,71
		220	0.28	0.99 lag	61		
3	Rectifier burden Lamp + Ballast	222	0.30	0.99 lag	85	68.2	2,41
		220	0.31	0.99 lag	84.94		
4	All expenses 1,2,3	222	1.72	0.62 lag	237	207	9.55
		220	0,94	0.99 lag	218		

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V. CONCLUSION

From the experimental results it can be concluded as follows:

1. In testing the motor load, COS phi can improve from 00:49 (lag) before mounting the capacitor, be COS phi 0.99 (lag) after the installation of capacitors and minimize current consumption from 1:22 A to 0.82 A.

2. In testing with TL lamps and rectifier load, COS phi is basically a system that is already well 0.92 (lag) and 0.99 (lag). After installation of the capacitor, COS phi be 0.99 (lag).

3. Testing the system with the entire load connected to the system, capacitor banks can increase the COS phi of 0.62 (lag) to 0.99 (lag) and can minimize current consumption of 1.72 A to 0.94 A.

4. Linear sensor readings are needed to get a quick response sat COS phi changes to the system.

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