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Review Scope on Design & Operation of Automatic Power Factor Controller Circuit with Artificial Intelligence using Fuzzy Logic

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Abstract: This paper shows the scope of making an automatic Power Factor controller with the help of Fuzzy Logic. A Single-phase PF circuit is taken for experimental purposes in two sets of capacitor banks. Single-phase supply connected to Induction Motor as load considering for power factor correction. Capacitor along with its circuit connected in parallel to the Induction Motor. Selection of capacitor is done based on multiplier table using K Factor along with initial Cosϕ of the load. Incoming control from MCB and current measurement are done at incoming as well as on capacitor banks individually. Seeking best selection, represent the relation between KVAr and µF. Results show we got desired permutations & combinations of data for making the FLC rule table. By this, we also thought about the industrial application using reactive power during the jerking load and sleep mode of machines.

Keywords: Power Factor, APFCR, Fuzzy Logic, PFC, FLC, Power Factor Correction

I. INTRODUCTION

Power quality is becoming very dynamic related to the load condition day by day, loads variances are from pure electrical (Inductive / Resistive) to hybrid load i.e. moreover moves to electronics control circuits. Because of a major segment is now work upon electronic control than power system absorbing the high frequency which leads to harmonic disorder. Our experiment is simply showing the scope of capacitor bank working practical along with all components, here trying to show that using L-C (Inductor - Capacitor) circuit we can correct the power quality precise efficiently. By practical experiment showing that how easily and from where we got the right data for making a set of orders to control in automatic mode. We can use FLC in many applications, but here, used in power factor correction for enhancing the load performance of an Induction Motor. Considering AI categorization than FL is the strongest AI system known as artificial general intelligence (AGI). Artificial Intelligence (AI) is commonly linked with our intelligence processes, means focused on three main skills i.e. learning, reasoning & self-correction. So to use of AI is very productive if we talk about any electrical system. Utilization of AI is to be done by making a set of orders as defined by the above three skills to taken into consideration all permutations & combinations to design an algorithm. In my work, I am using one AI-based application, named Fuzzy Logic.

II. LITERATURE REVIEW

This paper includes the past work done by various researchers. In [1] FLC superseded the PID controlling techniques with a fast steady-state by 0.05sec and power factor improvement by 0.15 Leading side. In the motor circuit, the power factor drops very quickly by FLC it gets the real-time pickup signal to exciter with real value to perform in the right manner [2]. FLC reduces the size of an oscillator with less setting time in the initial condition in compared to PID controller in 3 phase circuit in transmission network [3]. Membership function and rule table making so correctly that undershoot are removed instead of the control circuit in compared to PI controller [4]. In [7] FLC works best in closed-loop circuit instead of open-loop circuit by proving that overshoot 0% instead of 80%. In [8] FLC FPGA controller improved the THD from 73% to 5% and PF from 0.66 to 0.99. Power factor correction is done nearly unity in the operation of BLDC motor drive by using FLC [10]. In [11] fuzzy logic controller plays it significant role by improving the power factor from 0.9249 to 0.9987 in comparison to PI controller for the boost converter. For industries rarely implementation seen in any paper, but in [18] shown and proves that suitable size of the capacitor can be used according to the corresponding input variances, also FLC work efficiently in the correction of power factor from 0.7-0.75 to 0.9-0.978 in many application, also in 300HP motor major work done by achieving PF 0.9783 instead of 0.75leg. This project is further lead by inspiring from paper [19], which shows that power factor correction was done in a single-phase circuit using fuzzy logic control and as result observed that the THD around 2.6% along with PF 0.98leg. In single-phase, rectifier FLC is used with a boost converter by which THD improves tremendously from 36.44% to 0.42% and power factor from 0.9395 to 0.9999leg.

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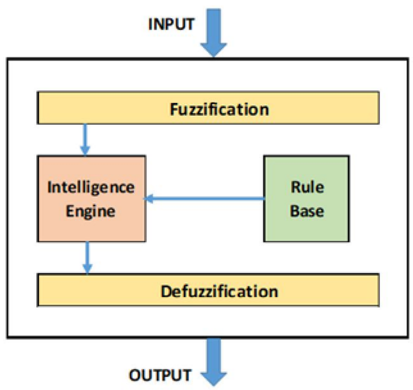
To improve power quality FLC plays a solid role by improving PF from 0.779 to 0.84 with regulated voltage at 239v from 165 to 225v using FC-TCR (SVC) [21].

After seen lots of improvement and seeing good results in the above works of literature, this is inspiring to do lead further to improvement for making atomization of capacitor bank for correction of power factor. As in addition to this project shows how to calculate the capacitor in µF as well as KVAr requirement according to load.

III.FUZZY LOGIC & IT'S USES

Fuzzy means vague or not so clear, at many stages situations are becoming so stringent that we could not conclude any single line statement as conclusion for true or false. General fuzzy logic block diagram shown in figure below. It has 4 components internally between input and output, output is obtain after processing data from input than through these components.



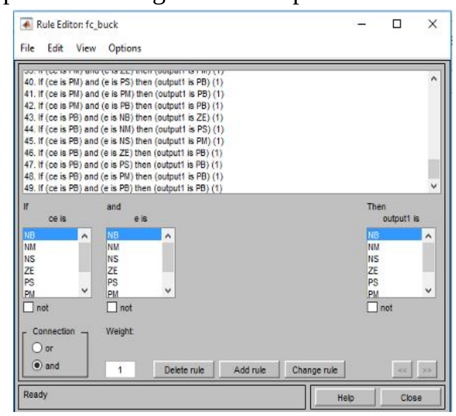


Fig. 1 – Fuzzy Logic Block Diagram

Fig. 2 – Fuzzy Logic 49 Rules Tables

Indian industries have a big potential to use such model for their respective application segment wise. There are many segments where these FLC systems are very useful. If we are considering the T&D (transmission and Distribution), there is large scope of FLC system as because from Generation to distribution via transmission there are big losses in the whole system. So demand vs supply always more than unity, which always shows requirement in generation but if we know the real cause than we can take appropriate step to take over on those issues. For those issue there are many uncertain inputs could be taken to execute these solutions, those uncertain inputs will be welcome by FLC System as because its input can be with many permutation and combinations. FLC system also knows as a member of AI (Artificial Intelligence), so after crossing the GO or NO GO remedies as solution we generally use common sense and this FLC system is after that very useful where many inputs plays to get the desired results.

IV.MOTIVATION & PROBLEM FORMULATION

By analysing a number of papers and journals it is seen that the Fuzzy Logic Based Power Factor Controller used in many application but I would like to use it in our Indian industries to improve the power factor at machine load, specially of process machineries which are not in linear nature of load in day time, as when these were started and stopped according to the line / product required operations. These industries are using conventional power factor controller for power factor improvement and these come late in power quality picture due to its feature of take time in analysis of load to compensate the power factor.

So, by Fuzzy Logic System will can help to improve the power factor very efficiently and accurately so that these industries can collect their sleeping money which is wasting in lagging or poor power factor.

My Main target is taken to save money by improving the power factor of M/s Tricolite Electrical Industries Limited, IMT Manesar, Gurugram on their Unit-3 which is a Fabrication and Paint Shop Section where are some servo motors, conveyor system, lifts etc. variable loads are installed and un-even load comes in day time. As an instant picture/ analysis in pre prediction comes that now these days plant is running with very poor power factor which is around 0.80Lagging to 0.85Lagging.

The objective of the thesis is to analyze the effect of different scenarios for Fuzzy Logic Based Power Factor Controller to implement in Indian industries for their nonlinear load compensation.

Now, from the preceding discussion of using the Fuzzy Logic Controller in Power Factor Controller, the dissertation objectives may be streamlined as follows on addition to the objective as above :

1) To develop 1-phase 230v and 3-phase 400v, 50Hz modular system of power rating in kW with reduced switching losses, reduced voltage and current stresses of semiconductor devices.
2) To develop the improved Power Factor in plant, the equipments/ machineries's life will increased because of these will comes in safe limit operation range.
3) To increase the efficiency of the equipments by lesser/ removal of shutdown time because of any over loading.
4) To develop an efficient PWM control technique for 1-phase as well as for 3-phase AC-DC PFC boost converters. A simple extended PWM technique overcomes
5) The sluggish response of PFC converters & also reduces the voltage stress of PFC boost converter components during transient periods with implementation of soft switching techniques in 1-phase AC-DC PFC boost converter
6) Topology employing active aux. circuit & passive snobbier circuit. This proposed technique will improve power density and efficiency for medium power applications.
7) Another main objective is to eliminate the voltage and/or currents stresses of boost semiconductor switches as well as semiconductor switches of auxiliary circuit itself. The proposed converters can achieve better efficiency at side load range.

V. EXPERIMENTAL PHYSICAL PROJECT WORK

Making a complete circuit with the logic of the power factor controller using an induction motor as load. This circuit consists of MCB, Contactors, Current Transformers, Voltmeter, Ammeter, and terminals with control wires along with connectors. First of all making drawings for project execution along with all circuits as below:-

A. General Arrangement (GA) with Nomenclature Used in Diagrams

General arrangement drawings (GA's) present the overall composition of an object such as a building. Depending on the complexity of the building, this is likely to require a number of different projections, such as plans, sections and elevations, and may be spread across several different drawings.

In PFC project we can see below that all main operational components are mounted on base plates and all metering components fixed of flap plate as considering a door arrangements.

A typical diagram of any circuit shows their respective components label marking which denoted the components name to identification on base plate to reflect in drawing because of size limitation on base plate. So for this project below are the nomenclature used to identify the components:-

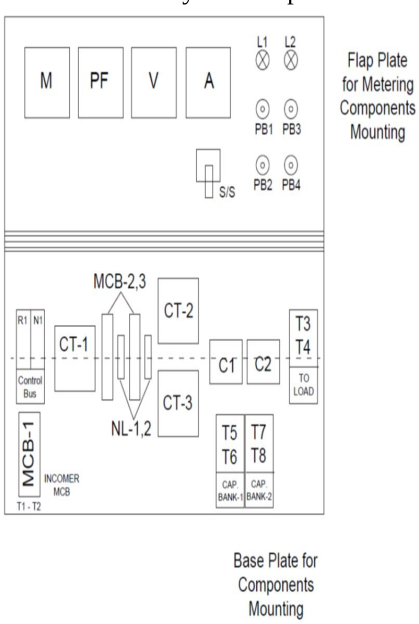


Fig. 3 General Arrangement Drawings

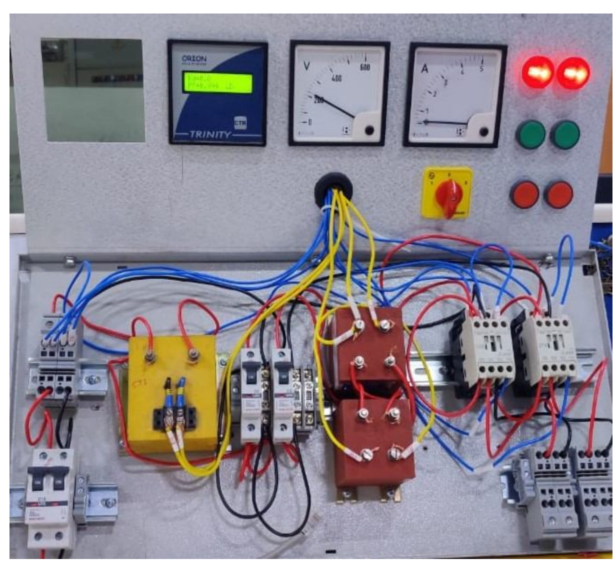


Fig. 4 Actual Project View

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MCB1 -	Miniature Circuit Breaker	- For Incoming Supply
MCB2 -	Miniature Circuit Breaker	- For Capacitor Bank-1 Control
MCB3 -	Miniature Circuit Breaker	- For Capacitor Bank-1 Control
CT1 -	Current Transformer	- Used for Main Sensing of PF
CT2 -	Current Transformer	- Used for Cap. Bank-1 Current
CT3 -	Current Transformer	- Used for Cap. Bank-2 Current
C1 -	Power Contactor	- Used for Cap. Bank-1 Circuit
C2 -	Power Contactor	- Used for Cap. Bank-2 Circuit
M -	Multifunction Meter AVF	- Main Metering Amp+Volt+Hz
PF -	Power Factor Meter	- To Measure Ckt Power Factor
V -	Voltmeter	- Main Volt Metering
A -	Ammeter	- To Measure Banks Current
S/S -	Ammeter Selector Switch	- To Select Bank for Current
L1,2 -	Indicator	- Cap. Bank-1,2 ON Indication
PB1-4 -	Push Buttons	- For Bank Operations
T1-8 -	Terminals	- For Load /Capacitor Conn.

B. Single Line, Power Line & Schematic Diagrams

A one-line diagram, also sometimes referred to as a single line diagram, is usually a single page that is a simple representation of a facilities electrical distribution infrastructure. It will have one single line shown for bus (or cable) to represent all three phases. Below is single line diagram of PFC Projects shown with all related component.

Power line diagram is the representation of a power system using the simple symbol for each component. The power line diagram of a power system is the network which shows the main connections and arrangement of the system components along with their data (such as output rating, voltage, resistance and reactance, etc.).

A schematic diagram is a picture that represents the components of a process, device, or other object using abstract, often standardized symbols and lines. Although schematic diagrams are commonly associated with electrical circuits, many examples can be found in other industries. For our PFC Project below are the schematic diagram showing all control process.

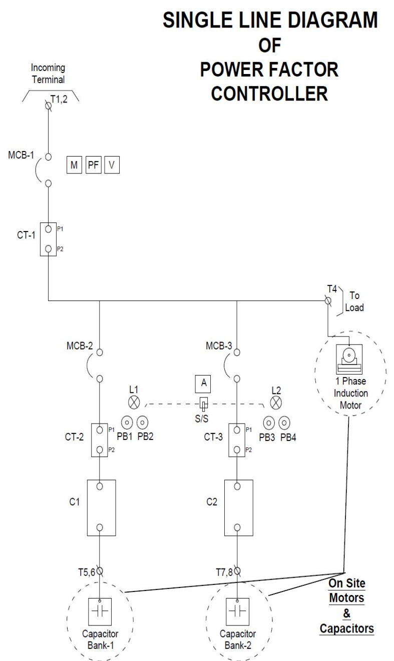

Fig. 5 Single Line Diagram (SLD)

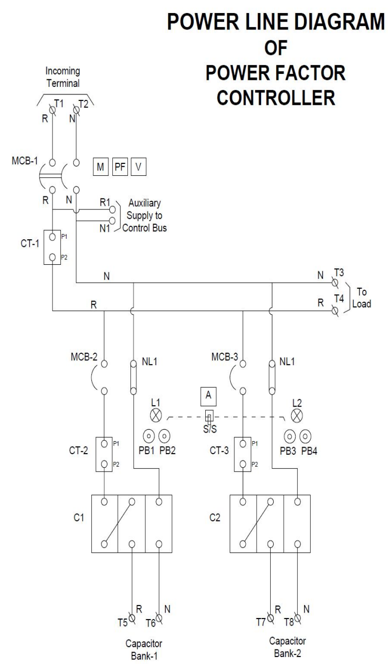

Fig. 6 Power Line Diagram (PLD)

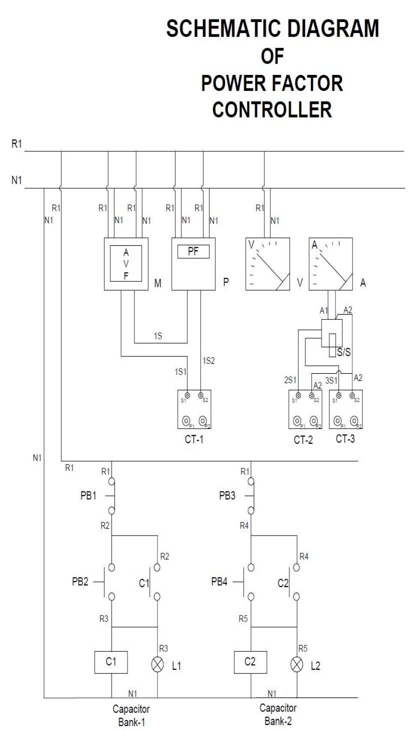

Fig. 7 Schematic Diagram

C. Bill of Material Used in Project

This project includes many type of electrical components and accessories, if we will not calculate and analysis its cost than future expansion will become tougher. So for a record and take a record we must calculate the project cost including its list of items specifications. Below are the components List with Quantity, specification & Costing in details:

TABLE I
BILL OF MATERIALS

S. No.	Component Details				
	Legend	Item Desc.	Rating	Make	Qty.
1	MCB1	MCB	16A, DP, C Curve	Anchor	1
2	MCB2,3	MCB	6A, SP, C Curve	Anchor	2
3	CT1	CT	10/5A, Resin Cast, WPL	Precise	1
4	CT2,3	CT	5/5A, Resin Cast	Precise	2
5	C1,2	Power Contactor	12A, TP, 230v AC Aux.	Mitsubishi	2
6	M	Digital Meter	AVF Meter	Schneider	1
7	PF	Digital PF Meter	0-5A, 230vAC Aux	Trinity	1
8	V	Analog	0-600v AC	Rishab	1
9	A	Analog Ammeter	0-5A	Rishab	1
10	S/S	ASS	6A, Ammeter Selector Switch	Selzer	1
11	L1,2	Indicating Light	Red, 230vAC Indicating Light	Essbee	2
12	PB1-3	Push Button	5A, Red Push Button	Essbee	2
13	PB2-4	Push Button	5A, Green Push Button	Essbee	2
14	Wire/Fab	Wires / MS	Connecting Wires / MS Sheet	Polycab/Misc.	1 Lot

VI. OPERATIONS PROCEDURE OF PROJECT

As we are prepared Power Factor controller and as if we are talking about operations or it's working than we have to follow one by one step from the schematic diagram and according to that we have to connect the supply at T1 & T2 as an incoming supply to charge the entire circuit for further operations. Before proceeding we have to not it down the exact reading of healthy circuit in our experimental log book. Also need to have complete look over each every components for proper tightness of all connections.

There another 6 terminal given in the complete circuit, so at T3 & T4 load will be connected with on its right polarity mean phase at 'Red wired terminal' and Neutral at 'Black wired terminal'. For better result we need to have to connect an inductive load i.e. induction motor, so for our project we taken motor rated around 1.5kW. Not there four terminals are balance T5 & T6 as well as T7 & T8, these are those terminal on which we have to connect the single phase capacitor as considering two banks reacting individually in the circuit. Now time to operate the circuit, as we can see there three CTs in whole circuit, co CT1 is for current sensing of whole circuit to calculate the Digital PF in meter fixed on its flap. One Digital AVF (M) meter also fixed over there to show the running Voltage Level, Current Level & Frequency. One additional analog Voltmeter also connected to check two method analysis from digital to analog for accurate as well as comparative value measurement. Another two CTs (CT2 & CT3) are connected on both bank individually to show there running current when capacitor comes in circuit to check their respective healthiness current drawn. One S/S is given there to check bank wise current rating by selection of CTs. There are L1 & L2 indicator are connected to show the 'ON' indication of the bank status wither comes in circuit by power contactor (C1 & C2) on. These both circuit will be start through green push buttons (PB2 & PB4) and stop through red push button (PB1 & PB3). So now motor need to connect at T1 & T2 and on the main MCB1 to run the circuit. As when motor gets started some will deflect over the 'M' mete and on 'PF' meter so record that reading as per previously format. At this moment we can see power factor is very low around 0.60 lagging so we need to add the capacitance to improve the power factor. For this we need to have to calculate the gap of desired PF (say 0.99 lagging) from the observed / running PF (say 0.6 lagging). Now we have to on one bank by pressing PB2 of Bank-1, as when Capacitor comes in circuit we have to note down the reading again.

Also if the desired /Targeted PF is not achieve than switch on another bank-2 by pressing PB4 and 2nd capacitor will come is circuit to achieve desired power factor PF. This is the complete operation of project "POWER FACTOR CONTROLLER".

VII. RESULTS AND DISCUSSION

Talking about the capacitor use in any circuit than we have to understand that w.r.t. voltage level capacitance will varies accordingly i.e. If we are using 57.8µFd capacitor than below are the capacitance comes in system w.r.t. voltage applied on it :

TABLE II
VOLTAGE VS KVAR VALUES

Votage Level	Capacitance	kVAr
@ 525 Volt AC	- 57.8uFd	- 5.00 kVAr
@ 480 Volt AC	- 57.8uFd	- 4.18 kVAr
@ 440 Volt AC	- 57.8uFd	- 3.51 kVAr
@ 400 Volt AC	- 57.8uFd	- 2.90 kVAr
@ 380 Volt AC	- 57.8uFd	- 2.62 kVAr
@ 230 Volt AC	- 57.8uFd	- 0.96 kVAr*

*We are using 0.96kVAr @ 230v AC in our project.

But now we have to better under understand how the capacitor will calculate on which load so we will lean by some examples just go through it.

TABLE III
FACTOR K (KVAR/KW)

	final cosφ											
initial cosφ	0.80	0.85	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
0.60	0.583	0.714	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
0.61	0.549	0.679	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
0.62	0.515	0.646	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.01 5	1.062	1.123	1.265
0.63	0.483	0.613	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.581	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.549	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
0.66	0.388	0.519	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
0.67	0.358	0.488	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
0.68	0.328	0.459	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
0.69	0.299	0.429	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
0.70	0.270	0.400	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.71	0.242	0.372	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.344	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.316	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.80		0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.84		0.026	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85			0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86			0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.87			0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88			0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89			0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.90				0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484

To calculate the desired rating of capacitors so we have to learn by some examples and two type of way to calculate the correct required capacitance to be added.

Taken a project example, A 3 Phase, 3 kW (P) Induction Motor has a PF of 0.75 lagging and we need to improve by 0.90 lagging. Now need to calculate the capacitance add in KVAr as per below methods:

A. By Simple Table Method

From Table, Multiplier from 0.75 to 0.90 is .398

Req. kVAR = 3kW x .398 = 1.194 kVAR, so for each phase = 1.194/3 = **0.398 kVAR**

B. By Classical Calculation Method

θ1 = Cos-1 = (0.75) = 41°.41; Tan θ1 = Tan (41°.41) = 0.8819
θ2 = Cos-1 = (0.90) = 25°.84; Tan θ2 = Tan (25°.50) = 0.4843
Req. kVAR = P (Tan θ1 – Tan θ2) = 3kW (0.8819 – 0.4843)= 1.194 kVAR, so for each phase = 1.194/3 = **0.398 kVAR**

Now need to calculate in µF, so take above result for calculating further values as below, required capacitor in µF:
C = kVAR / (2 π f V2) = (1.194kVAR) / (2 x π x 50 x 4002) = 0.2375 x 10-4 = 23.75 x 10-6 = **23.75µF**

OR by simple calculation method, kVAR = 1.194 … (i)
We know that; IC = V/ XC, Whereas, XC = 1 / 2 π F C
IC = V / (1 / 2 π F C) = V 2 F C = (400) x 2π x (50) x C = 125663.7 x C
And, kVAR = (V x IC) / 1000 … [kVAR = (V x I)/ 1000]
IC = 400 x 125663.7 x C = 50265.48 x C … (ii)

Equating Eq. (i) & (ii), we get, 50265.48 x C = 1.194C
C = 1.194 / 50265.48 = 0.2375 x 10-4 = 23.75 x 10-6 = **23.75µF**

C. Outcome / Results of project

Now, we have taken analysis with actual reading of test conduct with our project, results are as below during the test done:

Capacitor Rating:
Voltage = 230v AC, 1-Phase, 50Hz
µFd : 57.8 µFd
Current : 4.17 Amp
kVAr : 0.99 kVAr

Load Taken:
Voltage = 230v AC, 1-Phase, 50Hz
Rated : 1.5 kW
Current : 10.5 Amp
RPM : 1500 RPM

TABLE IV
Project Testing Results

S. No.	Condition	PF	Amp.	Watts	Remarks
1	Motor Running w/o Capacitors	0.644 lag	10	311	Legging PF in the System
2	Motor Runs with Bank-1	0.997 lag	9.71	290	PF Almost Corrected to Unity
3	Motor Runs with Bank-2	0.998 lag	9.69	291	PF Almost Corrected to Unity
4	Motor Runs with Bank-1 & 2	0.364 led	9.30	280	Leading PF in the System

VIII. CONCLUSIONS

After took test results, we observed that, by adding the Capacitor one by another power factor improved from 0.644lag to 0.997lag of an induction motor load as an inductive load in circuit and wattage reduced by 21 watts. When both capacitor added with the induction motor the power factor improved from 0.644 legging to 0.364 leading and wattages reduced by 31 watts. Here we studied all data with step-wise control of the power factor of an induction motor. Power factor of 1.5kW single-phase motor is improved from 0.644 legging to 0.997 legging by adding any one capacitor banks and upright improvement goes to leading was seen with two bank also. Using these data to make an algorithm to avoid any manmade mistake in the correction of power factor as well as the real-time correction will improve the power quality efficiently. Also, these all data with all permutations and combinations will help to make a ruling table to execute any automation process using AI techniques. Step-wise controls show that real-time adding will help to select the right rating with the right capacity of capacitor for power factor correction in an electrical system.

IX.FUTURE SCOPE

As a further scope we can move to below step to improve further this project:-

A. Complete project is now manual operation which can be easily converted in automatic mode by adding any Controller.
B. Complete project can be run by Fuzzy Logic to automat each back operation by making conditional sequences.
C. Now this is only with capacitance (C Ckt) units but we can also add reactor (L Ckt) to make it useful to remove /filter / control the system harmonics to connect in series with supply and capacitor. Than it will become Capacitor cum detuned Reactor (L-C Ckt) circuit.
D. As it is base unit and it can be further utilized to make switching by Thyristor to make it real time power factor panel which is very useful for the Furness industries and welding load industries etc.

Although we made a basic unit but it can extended in many way & I am also would like to move ahead to make it another level.

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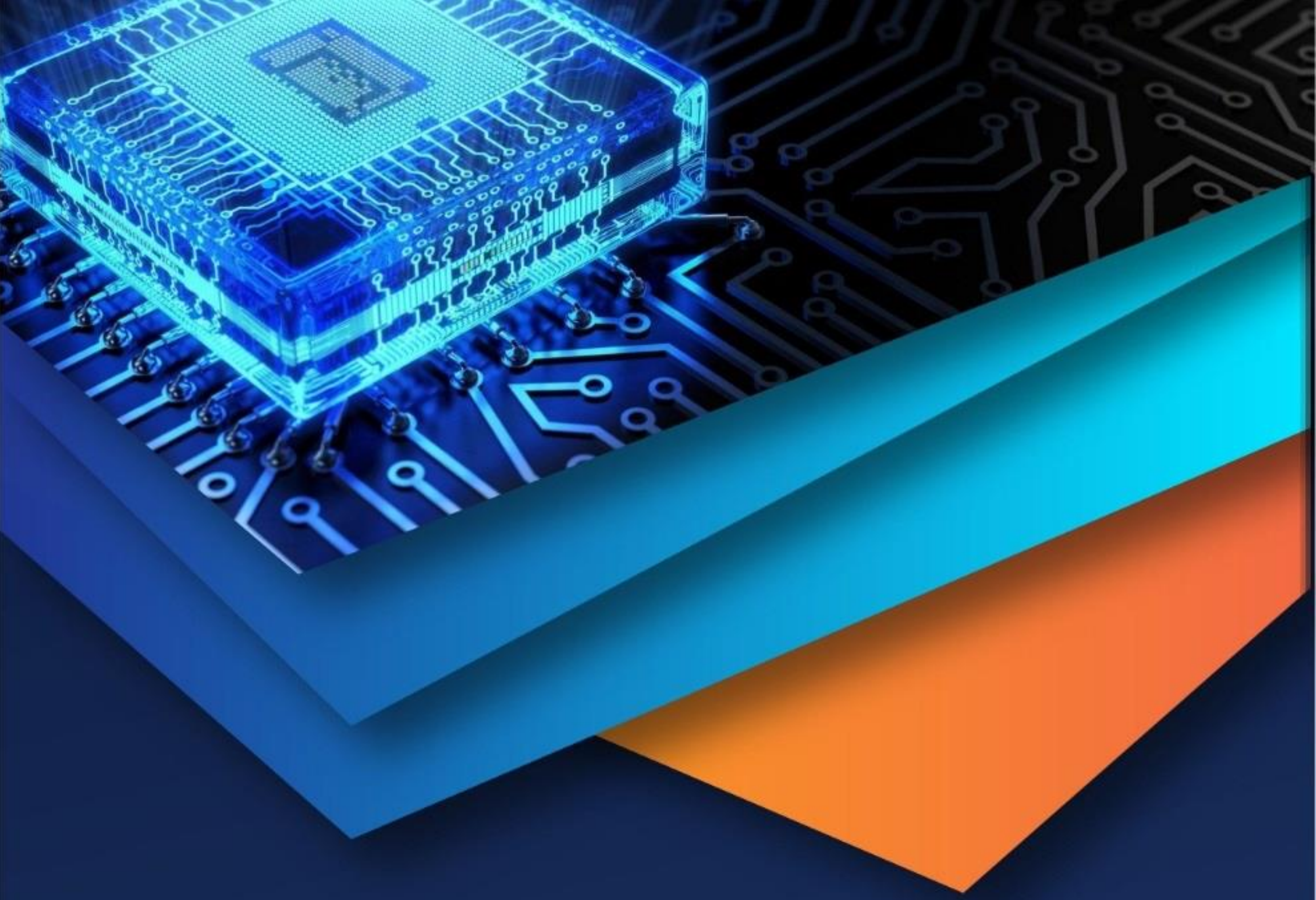

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