Power Factor IMPROVEMENT PANEL (PFI)

COMPREHENSIVE SOLUTIONS FROM DESIGN TO DELIVERY

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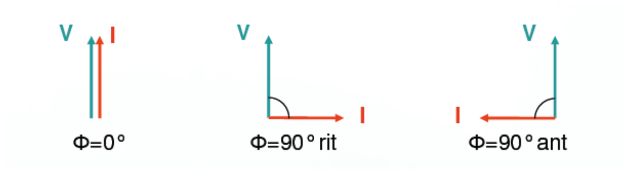
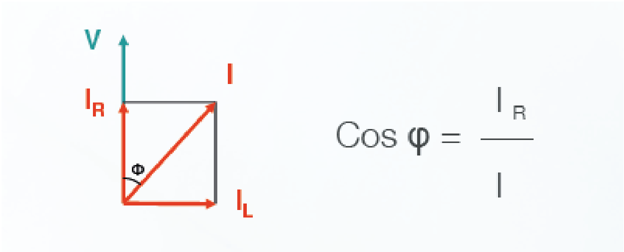
POWER FACTOR CORRECTION

The ecological importance of the power factor correction. In electrical circuits the current is in phase with the voltage whenever are in presence of resistors, whereas the current is lagging if the load is inductive (motors, transformers with no load conditions), and leading if the load is capacitive (capacitors).



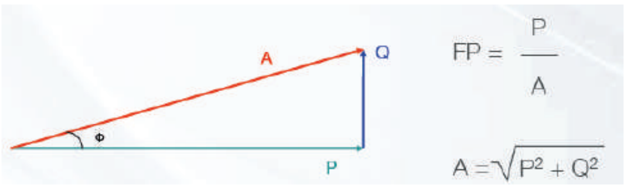
The total absorbed current, for example, by a motor is determined by vector addition of:



These currents are related to the following powers:
1. active power linked to IR;
2. reactive power linked to IL;

The reactive power doesn't produce mechanical work and it is an additional load for the energy supplier . The parameter that defines the consumption of reactive power is the power factor.

We define power factor the ratio between active power and apparent power:



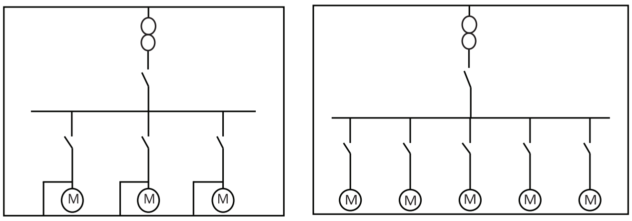
As for as there are not harmonic currents power factor coincide to cosφ of the angle between current and voltage vectors. cosφ decreases as the reactive absorbed power increases.

Low cosφ, has the following disadvantages:
1. High power losses in the electrical lines
2. High voltage variation in the electrical lines
3. Over sizing of generators, electric lines and transformers.

From this we understand the importance to improve (increase) the power factor. Capacitors need to obtain this result.

Description

By installing a capacitor bank it is possible to reduce the reactive power absorbed by the inductive loads in the system and consequently to improve power factor. It is suitable to have cosφ a little in excess of 0.9 to avoid paying the penalties provided for by the law. cosφ must not be too close to unity, to avoid the leading currents in of the electrical system. The choice of the correct power factor correction equipment depends on the type of loads present and by their way of working. The choice is between central compensation and individual compensation.

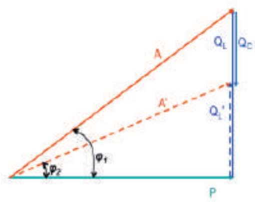


Individual compensation Central compensation

How many capacitor

The choice of capacitor bank to install in a system is closely depended from:
1. cosφ2 value that we would obtain
2. cosφ1 starting value
3. installed active power.

By the following equation:
QC = P * (tanφ1 - tanφ2)
Can be also written QC= k * P



QC = Required capacitors reactive output [kvar]; P = Active power [kW]; QL, Q'L = Inductive reactive output before and after the installation of the capacitor bank; A, A'= apparent power before and after the power factor correction [kVA]. As example if we have installed a load that absorbs an active power of 'P' kW having a power factor 0.7 and we want to increase it until our target 0.95.

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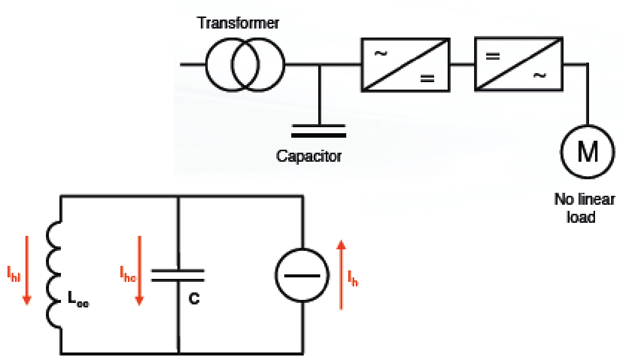
HARMONICS

The distortions of the voltage and current waveforms are generated by non-linear loads (inverter, saturated transformers, rectifier, etc.) and produce the following problems:

1. On the A.C. motors we find mechanical vibration that can reduce expected life. The increase of the losses creates overheating with consequent damaging of the insulating materials;
2. In transformers they increase the copper and iron losses with possible damaging of the windings. The presence of direct voltage or current could cause the saturation of the cores with consequent increasing of the magnetizing current;
3. The capacitors suffer from the overheating and the increasing of the voltage that reduce their life.

The waveform of the current (or voltage) generated by a non linear load, being periodical, could be represented by the sum of many sinusoidal waves (a 50Hz component called fundamental and other components with multiple frequency of the fundamental component so called HARMONICS).



It is not advisable to install the power factor correction without considering the harmonic content of a system. This is because, even if we could manufacture capacitors that can withstand high overloads, capacitors produce an increase of harmonic content, with the negative effects just seen. We speak about resonance phenomena when an inductive reactance is equal to the capacitive one.

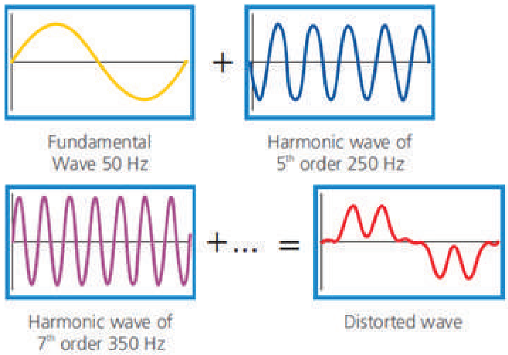
$$2\pi f\, L = \frac{1}{2\pi f\, C}$$

If a harmonic current In with the same frequency of the resonance in series exists, this one will be totally absorbed by the system capacitors-reactors without any effect on the network. The realization of a tuned passive filter is based on this simple principle. This application is required when we want the reduction of the total distortion in current (THD) on the system:

$$THD = \frac{\sqrt{I_3^2 + I_5^2 + I_7^2 + \dots I_n^2}}{I_1}$$

I_1 = Component at the fundamental frequency (50Hz) of the total harmonic current

I_3 , I_5... = Harmonic components at the multiple frequency of the fundamental (150Hz, 250Hz, 350Hz, ...)



The dimensioning of tuned/passive filters is linked to the circuit parameter:

1. Impedance of the network (attenuation effect less as the short-circuit power on the network increases.);
2. Presence of further loads that generate harmonics linked to other nodes on the network
3. Capacitor types;

On this last point we have to make some considerations. It is known that the capacitors tend to decrease capacity over time: varying the capacity inevitably varies the resonance series frequency and this drawback can be very dangerous because the system could lead in parallel resonance conditions.

$$f_{rs} = \frac{1}{2 * \pi * \sqrt{L_f * C}}$$

In this case, the filter does not absorb more harmonics but even amplifies them. In order to have a constant capacity guarantee over time we need to use another type of capacitors made in bi-metallized paper and oil impregnated polypropylene. In addition to the passive absorption filter realized with capacitors and inductances is possible to eliminate the network harmonics, with another type of absorption filter: the active filter. The operation principle is based on the inline injection of the same current harmonics produced by non-linear loads, but out of phase.

COMPENSATION

Individual for transformer

A typical example of power factor correction, sometimes not much considered but surely important, concerns the power factor correction of transformers for the distribution of energy. It is essentially a fixed power factor correction that must compensate for the reactive power absorbed by the transformer in its no load condition (this happens often during the night). The calculation of the needed reactive output is very easy and it bases itself on this equation:

Where $$Q_c = I_0\% * \frac{A_N}{100}$$

I0%= magnetizing current of the transformer
AN= Apparent rated power in kVA of the transformer. If we don't have these parameters, it is convenient to use the following table.

Power Transformer kVA	Oil Transformer kVAR	Resin transformer kVAR
10	1	1.5
20	2	1.7
50	4	2
75	5	2.5
100	5	2.5
160	7	4
200	7,6	5
250	8	7.5
315	10	7.5
400	12,5	8
500	15	10
630	17,6	12.5
800	20	15
1000	25	17.6
1250	30	20
1600	35	22
2000	40	25
2500	50	35
3150	60	50

Individual for motor

Another very important example of power factor correction concerns asynchronous three-phase motors that are individually corrected. The reactive power likely needed is reported on table

Motor power		Required Reactive power (kVAR)				
HP	kW	3000 rpm	1500 rpm	1000 rpm	75 rpm	600 rpm
0.4	0.55	-	-	0.5	0.5	-
1	0.73	0.5	0.5	0.6	0.6	-
2	1.47	0.8	0.8	1	1	-
3	2.21	1	1	1.2	1.6	-
5	3.08	1.6	1.6	2	2.5	-
7	5.15	2	2	2.5	3	-
10	7.36	3	3	4	4	5
15	11	4	5	5	6	6
30	22.1	10	10	10	12	15
50	38.8	15	20	20	25	25
100	73.6	25	30	30	30	40
150	110	30	40	40	50	60
200	147	40	50	50	60	70
250	184	50	60	60	70	80

Be careful: the capacitor output must not be dimensioned too high for individual compensated machines where the capacitor is directly connected with the motor terminals. The capacitor placed in parallel may act as a generator for the motor which will cause serious over voltage (self-excitation phenomena). In case of wound rotor motor the reactive power of the capacitor bank must be increased by 5%.

Centralized for plant

This method is well practiced in Bangladesh and the sub continent for being cost effective solution. Targeting not be panelized due to VAr compensation/Low p.f [<0.98%) issue all load sanction is being calculated considering Central PFI plant size to be 60% of the Main transformer VA. [example: Plant having 100kVA transformer will require 60kVAr Capacitor Bank. Most popular method of the centralized solution is to have step capacitor controller supported by magnetic contactor, Fuse with capacitor bank.

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COMPONENTS BASIC

Key components

For arranging a power factor specially for centralized combination of component needed, from activity point of view they have been categorized as active component, passive component & panel component.

Active component

Capacitor bank:

This is the item which provides the capacitive VAR compensation to the network, Based upon the network parameters [voltage, frequency etc] and condition type the capacitor used to be selected. Typical characteristics for a capacitor bank will be:

TECHNICAL CHARACTERISTICS	
Dielectric	Polypropylene metallized film
Winding connection	Delta
Safety device	Internal overpressure disconnector
Capacitance tolerance	-5%, +10%
Rated Voltage	230V
Rated Frequency	50 Hz
Over voltages	According to IEC Un + 10% (up to 8 hours daily) Un + 15% (up to 30 minutes daily) Un + 20% (up to 5 minutes daily) Un + 30% (up to 1 minute daily)
Over current	2xIn (including harmonics)
Maximum inrush current	Maximum inrush current 200xIn
Insulation level	3 / 12kV
Voltage test between terminals	2,15 Un, 50Hz, 10 seconds (routine test)
Voltage test between terminals	3,00 Un, 50Hz, 60 seconds (type test)
Voltage test terminals/case	3000V, 50Hz, 10 seconds
Dielectric losses	< 0.2 W/kvar
Temperature class	-25/D
Cooling	Natural air of forced ventilation
Permissible humidity	0.95
Service life	130.000 operating hours (hot spot 50°C)
Service life	100.000 operating hours (hot spot 50°C)
Altitude	above sea level 2000 m
Impregnation	resin filled, PCB free
Terminals	Terminal board / screws (D ≤ 65mm)
Mounting position	Vertical preferable for beer cooling
Protection degree	IP20 (only D ≥ 85mm)
Installation	Indoor
Discharge resistor	Included
Discharge me	< 3 minutes to 75V or less
Applicable standards	-1/2IEC 60831

Harmonic blocking reactor:

This is the item also contribute VAR but by inductive loading. Usually this item is used for specific industry where harmonic content are high and may harm a capacitor in operation, therefore this reactor is detuned to a specific frequency to block the harmful event on the PFI system (partially it compensate to the total system in that specific frequency only). This reactor is constructed by magnetized core, Coil with temperature sensor for safety. The selection of this item is based upon system voltage, harmonics and detuned. Commercially available % detuned are usually 3%, 5.5%.. Etc. Typical characteristics for a capacitor bank will be:

TECHNICAL CHARACTERISTICS	
Applicable standards	IEC 60076-6
Rated voltages	230-690V
Rated frequencies	50 Hz
Tolerance of inductance	±5%(mean value across three phases)
Linearity I lin= 1.6...1,8 In	I lin= 1.6...1,8 In
Insulation (winding -core)	3 kV
Temperature	class F (155°C)
Maximum Ambient Temperatur	40°C
Protection class	IP00 indoor mounting
Humidity	0.95
Cooling	Natural
Design	Three phase, iron core double air gap
Winding material	Aluminum foil/copper wires
Impregnation	Polyester resin, class H
Terminals	Terminal blocks, or cable lugs.
Temperature	All reactors are provided with a temperature switch (opening switch)seperate screw terminal for the which is located inside every coil
Switching temperature	140°C
Voltage	250Vac (<5A)
Tolerance	±5K
Detuned %	3%, 5.5%, 7%, 14% ..etc

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PASSIVE COMPONENT

Key components

Magnetic contactor:

This is the item which provides the advantage of switching of each stage to the network, Based upon the active items [Capacitor& Reactor] type the contactor used to be selected. A typical and most popular method of capacitor duty contactors are those have transient suppression capacity [High Peak Current Î]. This phenomena is well defined by AC6b utilization category of contactors having damping resistors. external Typical characteristics for a capacitor bank will be:

Technical Characteristic	
Applicable standards	EN/IEC 60947-1 / 60947-4-1
Rated voltages	230-690V
Rated frequency	50 Hz
Ulizaon category	AC-6b
Electrical switching frequency	240 Operating cycles/h
Electrical opera ting cycle	250000 (at Ue <= 440V)
Degree of protection	IP20
Operational temperature	-40...+70 °C
Mounting	DIN and plate mount
Damping resistor	Yes
Single Step - Peak Current Î	min <=30xIn to unlimited
Coil voltage	AC 50/60Hz &DC 24...440V
Cooling	Natural
Design	Three phase modular

The presence of harmonics and the network's voltage tolerance lead to a current, estimated to be 1.3 times the nominal current in of the capacitor, permanently circulating in the circuit where standard IEC 60831-1 Edition 2002 specifies that the capacitor must therefore have a maximum thermal current IT of:

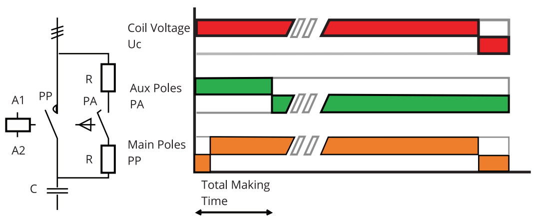

Fig.: Capacitor duty contactor

Electronic device used in state of contactor in the network for switching purpose with a specific application. Where high peak inverse voltage, faster switching response (<5ms) for immediate response, noise free with self-immune and expectation of high overall system lifecycle is a requirement than this solution is a must.

Immediate compensation of inductive reactive power is very often the only way to cope with disturbances imposed on the mains by huge, rapidly changing inductive loads. The thyristor switch module makes reaction times of 1...20 milliseconds possible. The switching is done, practically without reactive effects, at zero voltage level

(no voltage between input and output). The switch module usually has a very compact design, convenient connection, integral overheating protection, and LED indication for the switching signal and excessive temperature. Only considering factor is to take care of the device for over temperature inside the enclosure.

Technical characteristic	
Applicable standards	IEEE 428-1981
Rated voltages	230-525V
Rated frequency	50 Hz
Signal voltage	10-24V Vdc [20mA max]
Reacon me	5ms
Reswitching me	60ms
Peak Inverse voltage	2.2kV
Degree of protection	IP20
Operational temperature	-10...+40 °C
Mounting	Plate mount
Damping resistor	Yes if capacitor don't have
Coil voltage	AC 50/60Hz & DC 24...440V
Cooling	Force
Design	Three phase 2ware

Fig.: ABB UA-RA contactor

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PASSIVE COMPONENT

APFC relay:

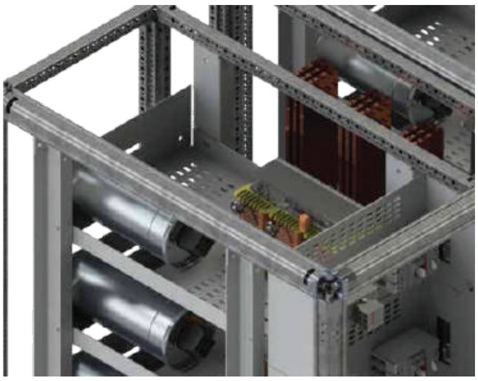
This device is the main discussion maker for step switching capacitor solution. The relay also called reactive power regulator is, together with the capacitors and reactors (in detuned filter cabinets), the key component of the automatic power factor correction system. It is in fact the "intelligent" element, responsible for the verification of the power factor of the load, in function of which controls the switching on and off of the capacitors batteries in order to maintain the power factor of the system beyond the target. The reactive power regulators RPC are designed to provide the desired power factor while minimizing the wearing on the banks of capacitors, accurate and reliable in measuring and control functions are simple and intuitive in installation and consultation. The flexibility of ICAR regulators allows you to modify all the parameters to customize its operation to fi t the actual characteristics of the system to be corrected (threshold power factor, sensitivity of step switching, reconnecting time of the steps, presence of photovoltaic, etc.).

Technical characteristic	
Applicable standards	IEC 61010-1
Rated frequency	50/60 Hz
Auxiliary voltage	AC 50/60Hz &DC 24...440V
Power consumption	~10VA
Switching me	5 - 600 s/step
Degree of protection	IP54
Operational temperature	-5...+55 °C
C/K	0.03 - 1.2 / Automatic
THD threshold	20% - 300% / OFF
Step coefficient	0/1/2/3/4/5/6/8/12/16
Mounting	Panel door mount
Electrical life [contact]	100000
Coil voltage	AC 50/60Hz &DC 24...440V
Cooling	Natural
Design	1CT 2PT / 3CT3PT for 3phase
Communication	Optional
Parallel operation	Optional

Panel component

In order to complete the solution for operation purpose panel has to be designed as per requirement of industry and application. Design consideration is highly based upon combinations of active components, space availability, aesthetic view, ease of operation & maintenance.

Technical characteristic	
Applicable standards	IEC 61921 for capacitor bank IEC 61439 for switchgear assembly
System voltage	400 - 1000V
Operational voltage	380 - 440V
Rated frequency	50/60 Hz
Auxiliary protection	Fuse / MCB / ISO-X / MPCB
Relay	Multistep
IP	IP 31 to 4X
Capacitor	Gasfilled with Discharge resistor
Reactor	Detuned reactor [for THD 3 / 5 / 7 / 11th]
Switching	Contactor [AC6b] / Thyristor
Cooling	Forces
Bus system	Copper
Installation	Floor mount free standing
Metering	Variable as per requirement
Operational voltage	Auto / Manual optional
Overall dimension	Variable as per requirement
Orientation	Non-Moduler / Moduler / PTT / Compartmentalized
Certification	BUET, CPRI ..etc



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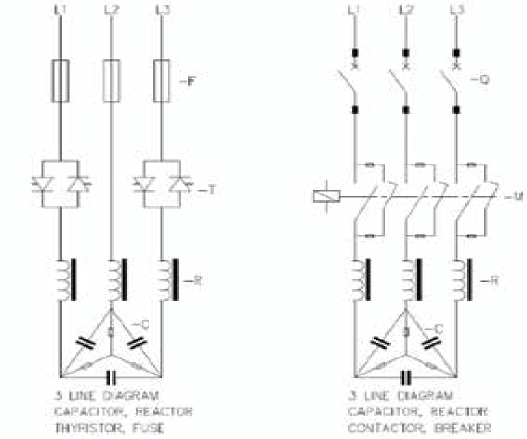
CONFIGURATIONS

3 line diagrams

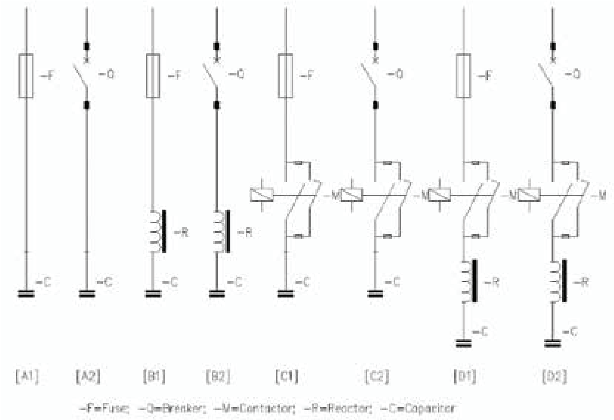
The basic configuration of power factor module has following items,

- Fuse [+F] or breaker [-Q]
- Contactor [-M] or thyristor switch [+T]
- Reactor [-R]
- Capacitor [-C]



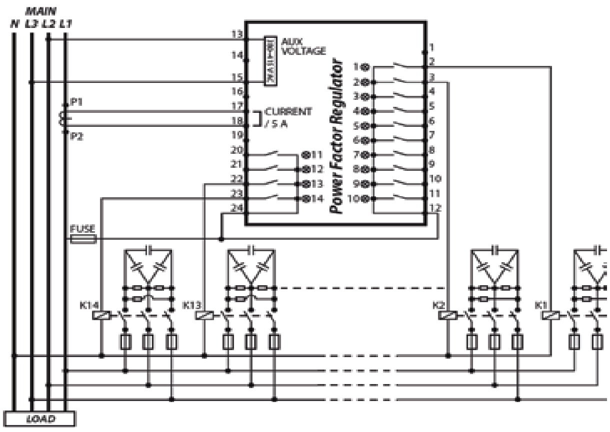
Component blocks

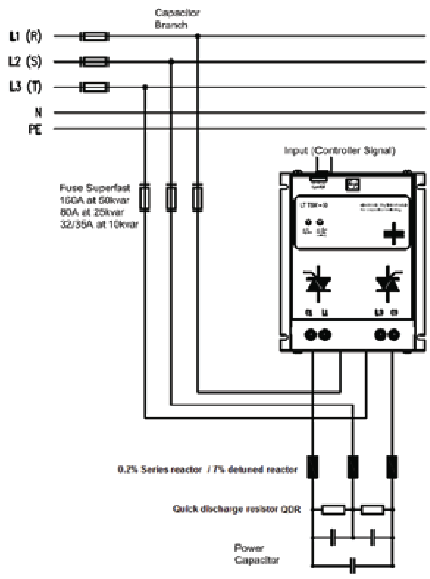
In order to complete the solution for operation purpose system has to be completed with following of any configuration applicable as per system requirement



Control diagram

The arrangement of stage control along with APFC





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SELECTIONS

Typical stage table

Transformer [kVA]	100	150	200	250		400	500			750	800			1000	1250	1500	1600			2000	2500				4000
PFI Size [kVr]	60	90	120	150	190	240	300	380	450	480	500	550	600	750	900	960	1000	1125	1200	1500	1800	1800	1900	2000	2400
Stage 00 [Fixed]	2.5	2.5	2.5	2.5	5	5	5	7.5	7.5	10	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	25	25	25	25
Stage 01	2.5	2.5	2.5	5	7.5	5	5	7.5	10	10	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	25	25
Stage 02	5	5	5	5	7.5	7.5	7.5	7.5	12.5	10	15	15	15	15	15	15	25	25	25	25	25	12.5	12.5	25	25
Stage 03	7.5	10	10	12.5	12.5	10	12.5	12.5	20	12.5	15	15	15	15	15	20	25	25	25	25	25	25	25	25	25
Stage 04	10	20	25	25	12.5	12.5	20	20	50	12.5	20	20	20	20	20	50	25	25	25	25	25	25	25	50	50
Stage 05	12.5	25	25	50	20	25	50	25	50	25	25	25	25	25	25	50	50	25	50	50	50	50	50	50	50
Stage 06	20	25	50	50	25	25	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	100	100
Stage 07					50	50	50	50	50	50	50	50	50	50	50	50	100	50	50	100	100	100	100	100	100
Stage 08					50	100	100	100	100	100	100	50	100	50	100	100	100	100	50	100	100	100	100	100	200
Stage 09								100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200
Stage 10										100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	300
Stage 11												100	100	100	200	200	200	100	100	100	200	200	200	200	300
Stage 12														200	200	200	200	100	200	200	200	200	300	300	300
Stage 13																		200	200	300	300	300	300	300	300
Stage 14																		200	200	300	300	300	300	300	400

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