



BEng Electrical & Electronic Engineering

Power Electronics & Drives

Design Exercise

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Task 1

Introduction & Background Information

The aim of this project is to specify a suitable technology for a factory motor drive system. The factory contains five induction motors as specified in the table below:

	Motor A	Motor B	Motor C	Motor D	Motor E
Power	500 kW	80 kW	10 kW	5 kW	1 kW
Phases	3	3	3	3	1
Voltage	400	400	400	400	230
Required to be Reversible?	Yes	Yes	No	Yes	No
Variable speed required?	Yes	Yes	Yes	No	No
Quantity Installed	5	10	23	17	127
Example Application	Rolling Mill	Gantry Crane	Conveyor	Cutting machine	Pumps / Fans

An induction motor is a commonly used AC electric motor in which the electric current in the rotor needed to produce torque is obtained via electromagnetic induction from the rotating magnetic field of the stator winding. The rotor of an induction motor can be a squirrel cage rotor or wound type rotor[1]. A motor drive is the electronic device that harnesses and controls the electrical energy sent to the motor. The motor drive feeds electricity into the motor in varying amounts and at varying frequencies, thereby indirectly controlling the motor's speed and torque[2]. When considering an electric induction motor, it is important to be able to vary the speed, torque and potentially reverse the direction of the rotation. In a scenario where motor control such as this was required, the usual motor technology of choice for a long time was a dc motor as it was easy to regulate through varying the input voltage and polarity [2]. Unlike a dc motor, the speed, torque and direction of an ac motor isn't as simple to regulate as, with an ac motor, the variables are dependent on the ac line frequency. However, with the development of variable frequency drives, this allowed for control over ac motors direction, torque and speed. The variable frequency drive achieves this through changing the frequency or duty cycle of the electrical energy the motor receives [3].

Starters

In the case that an induction motor is switched on directly from the supply, it can be subjected up to 7x the full load current and only develops a torque which is approximately 2 x the full load torque. A large voltage drop is produced in the line as a result of the large starting current, this could potentially disrupt

other devices that are connected to the same line. With this in mind, it is not advisable to start induction motors of higher ratings (generally above 25kW) directly from the mains supply[4].

Starting Methods

For small induction motors, it is reasonable to start them direct-on-line (DOL) as discussed above. For larger induction motors, there are three methods to ensure startup is carried out safely.

The first method is using primary resistors in order to drop some voltage and therefore apply a reduced voltage to the stator. Due to Ohm's law ($V=I/Z$), as the voltage drops, the starting current will also reduce by the same amount and the starting torque becomes a quarter of the normal voltage value. When applied, this method causes small induction motors to start smoothly. This method is perfectly suited for small induction motors.

The second method is auto-transformers, also known as auto-starters. It is suitable to use these with either a star or delta configured squirrel cage motor. It uses the principle of a three phase step down transformer alongside several taps that allow the user to start the motor in increments of the line voltage. A feature of the auto-transformer starting procedure is that the current drawn from the supply line is always less than the motor current. The difference between the supply line and the motor current is the transformation ratio.

The third method is known as a star-delta starter. It is designed to be used with motors that run on a delta connected stator. This method uses a two-way switch in order to connect the stator winding in star while starting and connect the stator winding in delta while running at normal speed. When connected to star, the voltage supplied to each phase in the motor gets reduced by a factor $1/(\sqrt{3})$ compared to the windings connected in delta. As a result the starting torque is $\frac{1}{3}$ times the delta connected windings[4].

Common Dc Bus

Interlinking the dc bus between VFDs via a fused connection establishes what is known as a common bus. The main benefit of a common bus is the sharing and balancing of power. For example, if a system with two VFDs and two motors is considered; one motor may be in a motoring state while the other motor is in a regenerating state. In this case, a common dc bus is useful in that the motoring VFD consumes the regenerative power instead of pulling from the grid [5].

Protection

Human safety is the top priority when protection is considered and so preventing injury and fatality is paramount. When devices are considered, the objective should be to permit normal operating conditions and isolate the equipment in case of abnormal conditions. There are 6 device protection variables to consider here:

- Overload protection: this is necessary to protect against the motor overheating when faced with an increased mechanical load. The protection here can disconnect the motor from the main power supply. This prevents excessive motor temperatures, thus preserving the windings and other integral parts.
- Overcurrent protection: this is necessary to protect users from potential electric shocks and the components from high currents. The protection here takes form in a circuit breaker or fuse and will trip or blow in a scenario where the current exceeds the amp rating.

- Low voltage protection: this is necessary to protect the motor's components in the scenario that the voltage decreases and the amperage therefore increases and risks causing potential malfunctions. The protection here is a device which is used to disconnect the motor from the voltage or power source
- Phase failure protection: this is necessary in order to protect the motor in the scenario that one phase fails and causes the other phases to deliver more current to the circuit which could potentially burn out the motor. The protection here will disconnect the motor from the power supply in a situation where a phase fails
- Phase reversal protection: this is necessary in order to protect against the motor turning in the undesired direction. The protection here detects opposite rotation of the motor and subsequently disconnects the motor from the mains supply.
- Ground fault protection: this is necessary in order to protect the circuit from receiving an excessive amount of current that may occur in the case of a short circuit. The protection here identifies a ground fault and disconnects the motor[6].

Solution to the Task

In identifying a suitable technology for the motor drive system, the motor's requirements must first be considered. There are five types of inductive motors. Four of the motors, A-D, all require the same voltage (400V) and three phases. These motors differ in their power rating, ranging from 5kW to 500kW. The fifth motor, E, is the smallest and only requires 230V, 1kW and 1 phase. Motors C and E do not need to be reversible and motors D and E do not require their speed to be variable.

ABB Industrial Drivers

The first company researched was ABB Industrial Drivers. Of the range of drivers that they have available, there is the ACS880 model range with drivers that are rated from 0.75kW to 250 kW. Initially this model seemed plausible due to their compatibility and flexibility along with their wide range of applications. For example, it is stated that they are suitable for use with devices such as cranes, which would have been applicable to the factory. However, these drivers were obviously not suited to fulfill the needs of the factory as the largest motor that the specified factory contains is a 500kW motor, far exceeding the largest driver that ABB provides .

Company website: [ACS880](#)

Altivar

The second company researched was Altivar. Their 71 plus model has drivers rated from 90-2000kW, thus. They can be fitted with IP 55 protection meaning that the devices are partially protected from the

ingress of dust as well as water at a 'jet' level. This is fairly high on the IP scale and means that the drivers are applicable in relatively harsh factory environments. Despite having a good all-round selection for the motor driver, this model is not suitable for the factory in question as it does not provide a driver small enough to accommodate the smallest motor within the factory.

Company website: [Altivar 71 Plus](#)

Sprint Electric

The third company researched was Sprint Electric. Their PL/X series carries a wide range of drivers whose output powers range from 5kW to 980kW and claim to have the best power density on the current market. The drivers in this series are available in both 2Q single direction and 4Q fully regenerative options. This means that the power configuration of the 4Q allows these drivers to be connected via a common dc bus that offers applications such as regenerative braking, thus sharing the balance of power along the bus. This allows for the drive to motor and brake in forward and reverse and regenerate energy into the mains supply when braking.

As standard, this series comes with analogue inputs and outputs. The outputs include: 4 total (resolution 2.5mV+sign) and 1 armature current output – 3 of which are configurable. All outputs are short circuit protected. There are eight total analogue inputs, all of which are configurable and all have programmable thresholds. All of the analogue inputs are over-voltage protected and can be utilised as digital inputs. The series has seventeen digital inputs and seven digital outputs, all of which are configurable. The digital outputs have protection from circuit shorting as well as protection from high temperatures and voltages. The PL/X series also includes information gathering and monitoring capabilities. They are able to monitor all of the analogue I/O voltages, as well as all of the digital I/O states. It can also measure the motor armature current, motor field current, motor armature volts as well as the total output power and ac supply faults. This information gathering capability allows for constant observation of the motors and the system's status, thus enabling accurate system configurations and collective safety monitoring. Finally, the PL/X series also includes advanced communication abilities. It achieves this through implementing such technologies as RS232, Profibus and Ethernet/IP plus many more. These communication technologies allow connected devices to communicate with one another, giving real-time feedback of the system, as well as user interaction over the whole network. The PL/X DC motor controller uses closed loop control of armature current and feedback voltage to give precise control of motor torque and speed.

[PL/X & JL/X RANGE](#)

In addition to this, the company also manufactures a 340/680/1220 Series, which includes a single phase driver that has an output power up to 1.8kW and is fully compatible with the PL/X series. As with the PL/X series, this series also incorporates a 4Q option. This option variant (XRI) also allows for regenerative braking. Across the two compatible series, this covers the range of drivers needed to meet the requirements of the factory.

[340/680/1220 Series Archives](#)

Motor A

Motor A is used in a rolling mill operation in which 5 drivers are required, 1 for each of the 5 motors. PL/X 520 has been chosen for this application as it is a 4Q dc drive that enables the motors speed to be controlled and its direction to be reversed. The driver works with a supply voltage between 12v-500vac, and an output power of up to 520 kW.

<https://www.sprint-electric.com/product/plx520/>



Motor B

Motor B is used in a gantry crane operation in which 10 drivers are required, 1 for each of the 10 motors. PL/X 85 has been chosen for this application as it is a 4Q dc drive that enables the motors speed to be controlled and its direction to be reversed. The driver works with a supply voltage between 12v-500vac, and an output power of up to 85 kW.

<https://www.sprint-electric.com/product/plx85/>



Motor C

Motor C is used in a conveyor operation in which 23 drivers are required, 1 for each of the 23 motors. PL/X 10 has been chosen for this application as it is a 4Q dc drive that enables the motors speed to be controlled and its direction to be reversed. However this ability to reverse the direction of the motor is not required for motor C. The driver works with a supply voltage between 12v-500vac, and an output power of up to 10 kW.

<https://www.sprint-electric.com/product/plx10/>



Motor D

Motor D is used in a cutting machine operation in which 17 drivers are required, 1 for each of the 17 motors. PL/X 5 has been chosen for this application as it is a 4Q dc drive that enables the motors speed to be controlled and its direction to be reversed. However this ability to control the speed of the motor is not required for motor D. The driver works with a supply voltage between 12v-500vac, and an output power of up to 5 kW.



Motor E

Motor E is used in pump and fan operation in which 127 drivers are required, 1 for each of the 127 motors. 1220XRi has been chosen for this application as it is a 4Q dc drive that enables the motors speed to be controlled and its direction to be reversed. However this ability to control the speed of the motor and reverse its direction is not required for motor E but, it having the 4Q capabilities means the drivers can be connected via a common dc bus allowing for regenerative braking. The driver works with a supply voltage between 200v-264v, and an output power of up to 1.8 kW.



Discussion & Conclusions

It is beneficial to acquire all components from the same company in the interest of establishing one point of contact for any potential issues. The drivers listed above have met the basic requirements listed for the specification as well offering a wide range of features that are advantageous in the overall running of the factory. For example, the PL/X series incorporates powerful ethernet which falls under Sprint Electric's smart automation, meaning that their PL/X drivers are fully equipped for the Industrial Internet Of Things (IIOT). This allows the drivers to be involved in a network that enables drive setup, machine process, virtual wiring and virtual panels. All of these add to the potential capabilities that a factory could benefit from. There are several protection devices integrated within the PL/X drivers, such as overcurrent protection and overload protection. This means that these devices are supported by the initial research. However, although all the requirements have been met, the drivers could potentially be improved in having more integrated safety features, as outlined in the initial research. Furthermore, the overall functionality of the factory could potentially be improved had the driver for Motor E matched the specifications of the other four drivers. Nonetheless, the drivers selected will perform as required.

Task 2

Introduction & Background Information

A variable frequency drive (VFD) is a device that uses a rectifier in order to convert AC voltage into a DC voltage [7]. In order to discuss VFD, it would be useful to first explain some of the main components. A variable frequency drive uses various components based on its performance requirements, these include;

Diodes

A rectifier diode is a two-lead semiconductor that allows current to pass in only one direction. Generally, the P-N junction diode is constructed through joining together n-type and p-type semiconductor materials. The P-type side is referred to as the anode and the n-type is referred to as the cathode. Rectifier diodes are a vital component in power supplies as they are necessary to convert AC voltage to DC voltage [8].

Thyristors SCRs

A thyristor is a device that is similar to a diode in that it also uses semiconductors. However, whereas a diode is either on or off, a thyristor can be used to control current passing through in a graduated manner. It accomplishes this by firing (switching on the thyristor) at a precise time, which in turn controls the conduction angle. The way in which thyristors are used within the circuit will affect the level of control and this varies with a given application. Half-controlled rectifiers use thyristors in place of diodes on either the positive or negative side of the circuit, whereas a fully controlled rectifier uses thyristors entirely [9].

IGBTs

An insulated gate bipolar transistor (IGBT) is a semiconductor with three terminals that function as switches that move electrical current. The role of the gates is to open or turn on when voltage is applied, creating a path between the layers. The voltage has to be above a specific threshold, otherwise the gate stays closed preventing the flow of electricity. In this way, an IGBT behaves like a switch; on when the gate is open and flowing current and off when it is closed [10].

Comparison

Of these three components, the diode is the most simple and therefore thyristors and IGBTs are often used in more complex operations. In terms of comparison, there are several reasons why thyristors and IGBTs may be used above a diode. Firstly, when comparing a diode to a thyristor, the thyristor allows for control over the output voltage as the phase angle firing can be controlled. This is advantageous in that within a rectifier, a thyristor enables the average voltage output to be changed. A further comparison between the thyristor and the diode is that a thyristor is well suited to applications such as charging systems, temperature control and energy lighting systems due to its capable function with high current and high voltage. Whereas diodes are better suited to situations such as radio demodulation, power conservation, overall voltage protection and use within logic gates [11].

When comparing an IGBT to a thyristor, a noticeable difference is that an IGBT only has a singular PN junction, whereas a thyristor has 3. IGBTs and thyristors are similar in that they can both be used in high power applications where they control currents. However, IGBTs are better suited to situations such as dc and ac motor drives compared to thyristors which are better suited to converting alternating power into alternating power of different frequencies and amplitudes. Finally, a key difference between the two is that an IGBT needs a continuous supply of gate voltage whereas a thyristor only needs a pulse to change its gate into a conducting mode [11].

Harmonics and Power Factor

Power factor is the ratio of real power to apparent power in an electrical system. The lower the power factor, the higher the current draw [12]. Through rectification, non-sinusoidal complex waveforms are constructed by adding together a series of sine wave frequencies known as Harmonics [13]. Power quality is most often represented as harmonic distortion, which represents the deviation between the ideal sinusoidal waveform the network voltage or the load current should have, and what really it is [14]. Harmonic noise can, however, be minimised through careful rectifier design.

Solution to the Task

Fig A shows a 6 pulse rectifier designed made using proteus. The three incoming supplies represent a delta configuration as all three are 230v and 50Hz but are 120 degrees different in phase angle. The design is referred to as a 6 pulse rectifier as there are 6 pulses produced per singular sinusoidal wave from the delta source as shown in fig B.

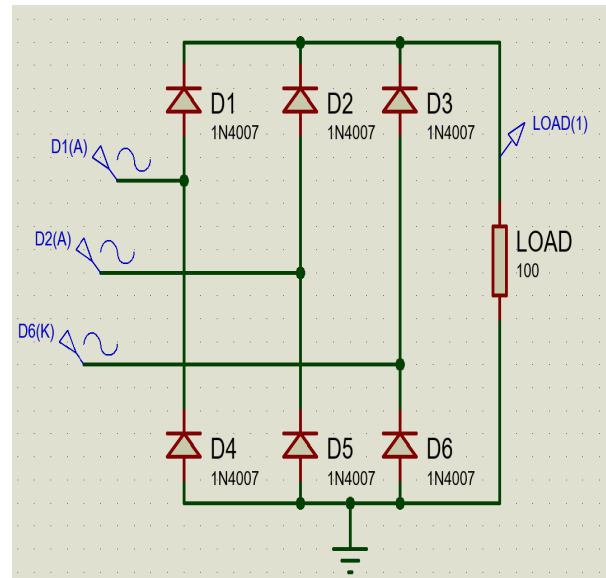


Fig A

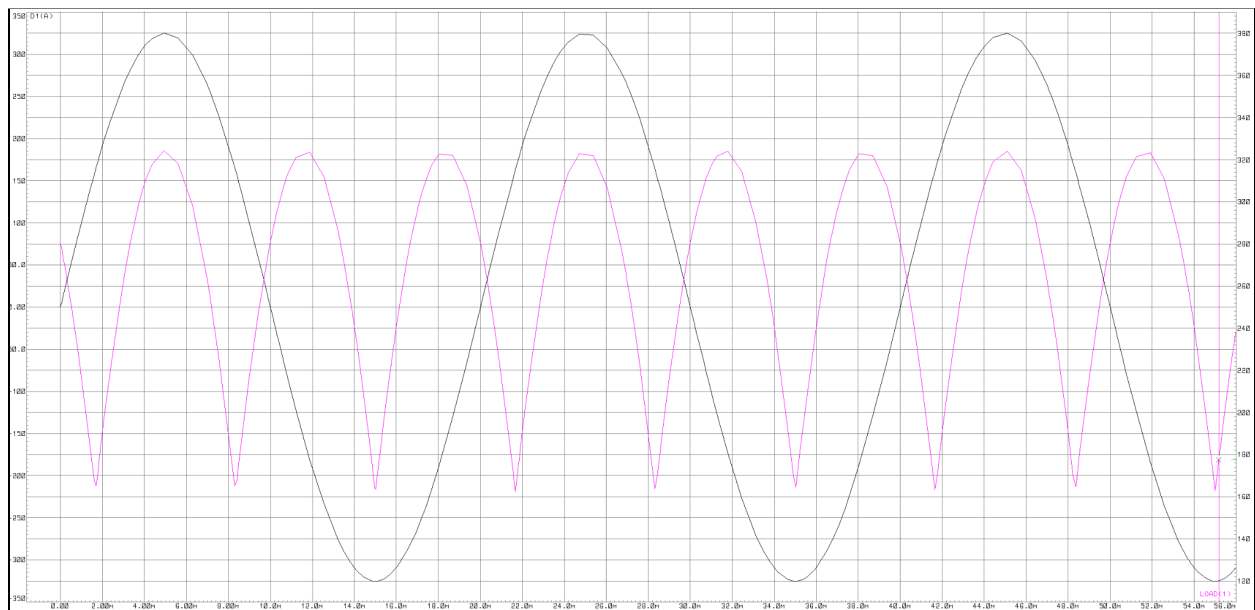


Fig B

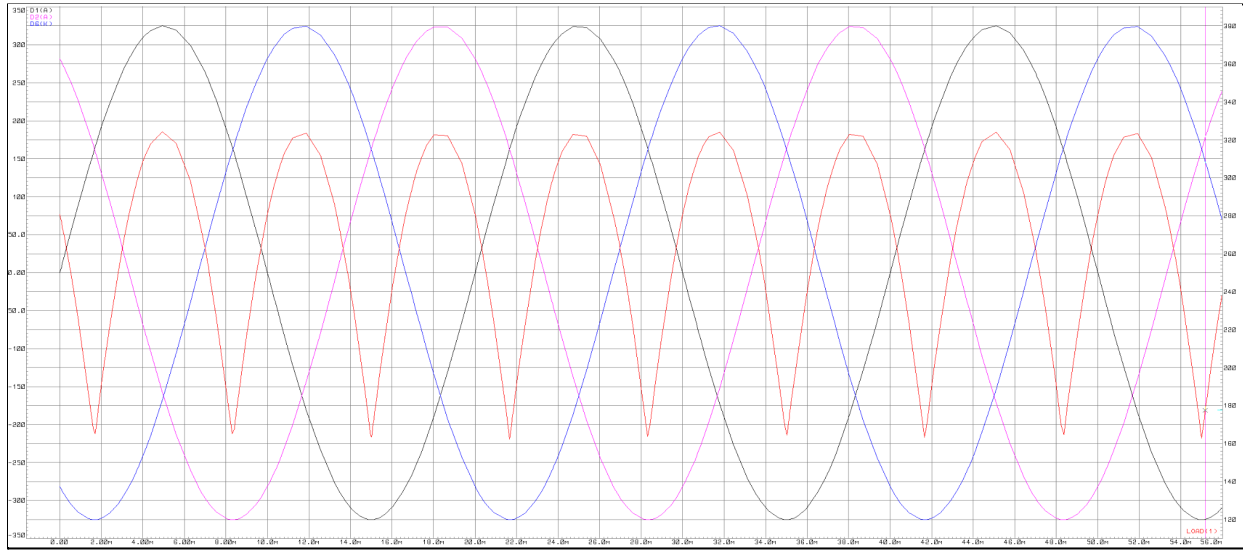


Fig C

Fig C shows the 3 sinusoidal waves of the incoming delta supply. These waves have an amplitude of 325 and a wavelength of 20m. The small signal between the sinusoidal waves is the load voltage produced by the rectifier. This wave does not drop below 0 as the sinusoidal source does, its amplitude lies between 163 and 323, this means the rectifier was successful in producing a more stable signal.

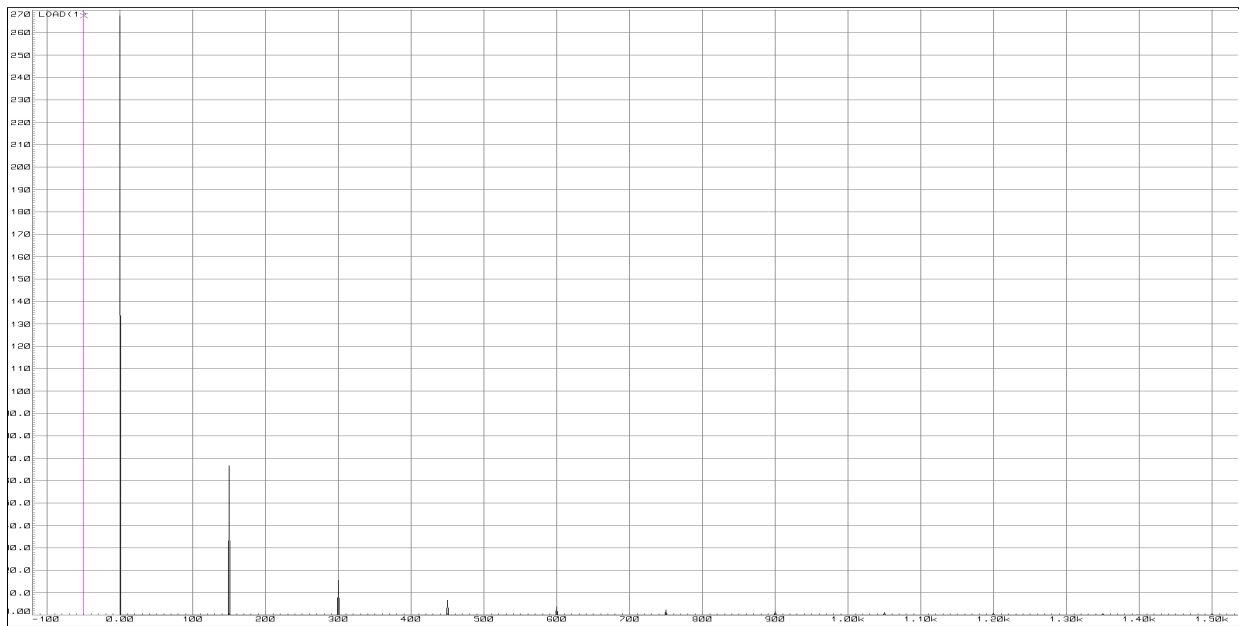


Fig D

Fig D is a fourier analysis graph which shows the harmonics produced as a by product of the rectifiers process.

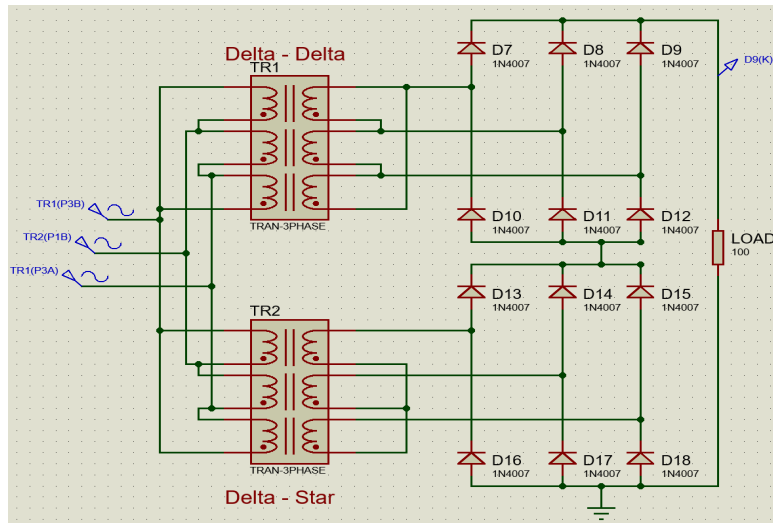


Fig E

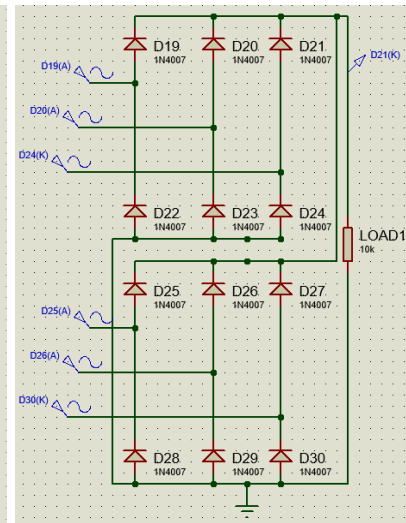


Fig F

Fig E is a 12 pulse rectifier made up from two 6 pulse rectifiers connected together. It is driven from a multi tapped transformer - a transformer with two sets of secondary windings and one set of primary windings. The primary windings are set up in a delta configuration and the first of the secondary windings are also set up in delta configuration. The second secondary windings are set up in star configuration. The reason for having the two secondary windings set up as one star and one delta is that it produces another phase shift resulting in 6 different phases going into the rectifier. When attempting to simulate this within proteus, the simulation would not run due to the multi tapped transformers. In order to overcome this, the initial design had to be adapted in order to be able to simulate the effects of the rectifier. As shown in Fig F, this was achieved by adding 6 sinusoidal sources which were 60 degrees out of phase from one another and connecting them to two 6 plus rectifiers.

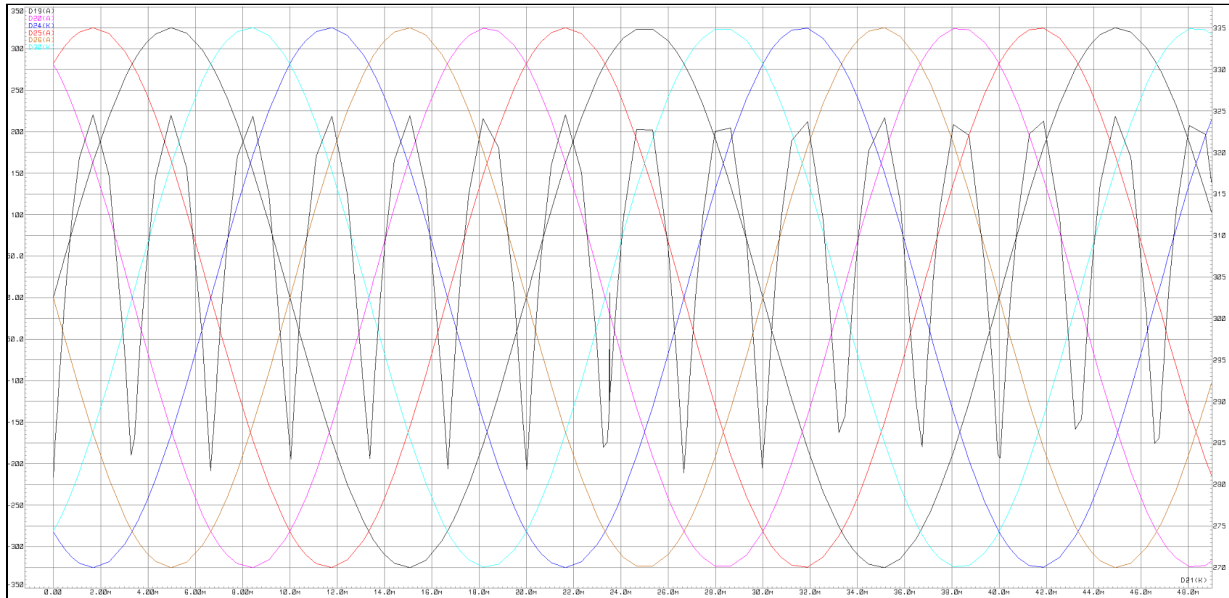


Fig G

Fig G shows the 6 sinusoidal waves and the 12 pulse rectifier output. In comparison with the 6 pulse rectifier the 12 pulse rectifier has doubled the number of pulses per wavelength, shown in Fig H, and changed where the amplitude lies between. Previously it was between 163 and 323, and after going through the 12 pulse rectifier it now lies between 285 and 324, this improvement has further smoothed the rectifiers signal output to the load.

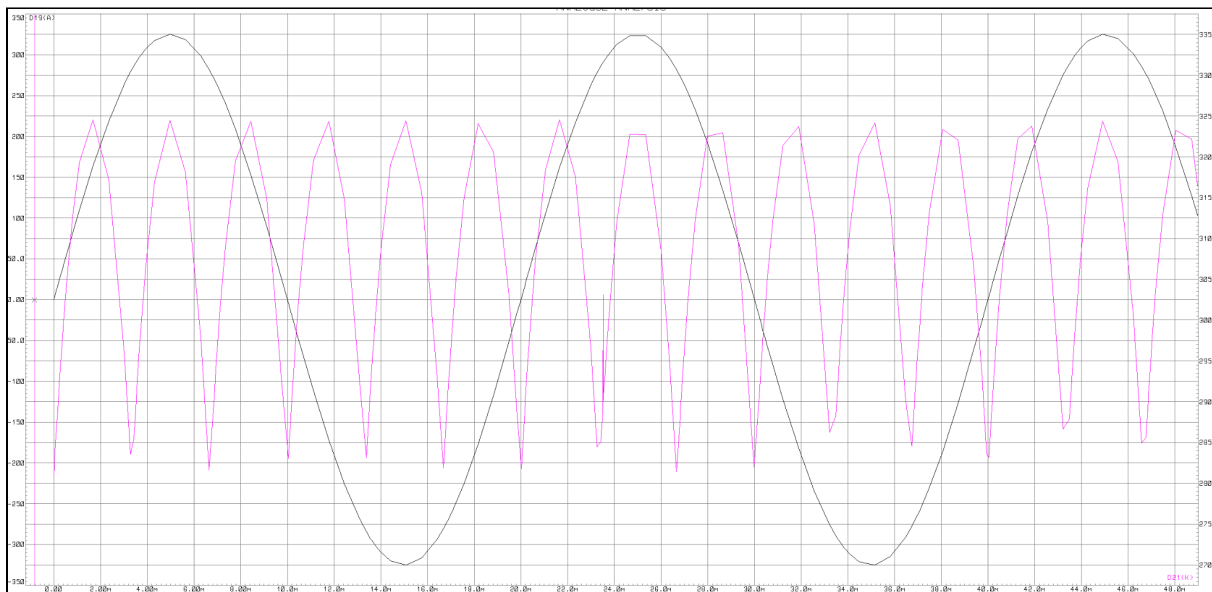


Fig H

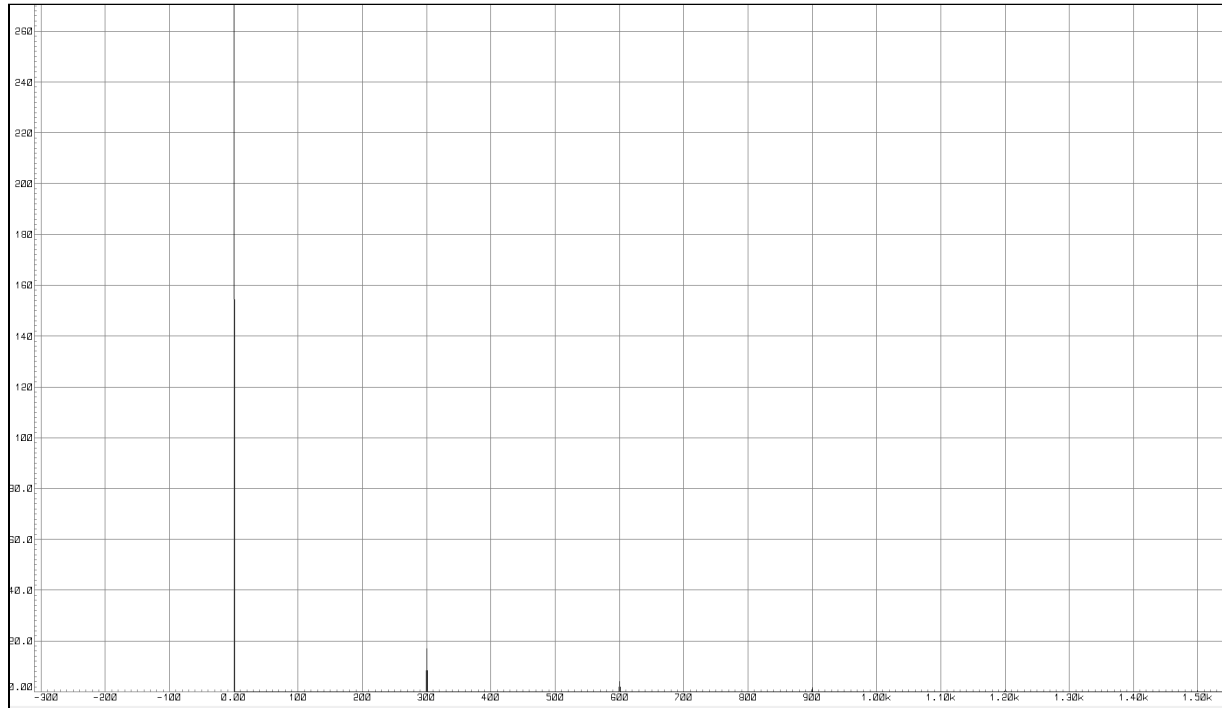


Fig I

As well as further smoothening the signal output, the improved rectifier has also reduced the frequency of the harmonics produced as a byproduct.

References

- [1] 2021. *Induction Motor: Working Principle, Types, & Definition*. [online] Available at: <<https://www.electrical4u.com/induction-motor-types-of-induction-motor/>>
- [2] Mraz, S., 20210. *What's the Difference Between a Motor and a Drive?*. [online] Machine Design. Available at: <<https://www.machinedesign.com/motors-drives/article/21834283/whats-the-difference-between-a-motor-and-a-drive>>
- [3] Herres, D., 2019. *Variable Frequency Drives: Viewing the DC Bus*. [online] Testandmeasurementtips.com. Available at: <<https://www.testandmeasurementtips.com/variable-frequency-drives-viewing-dc-bus/>>
- [4] Daware, K., 2016. *Starting methods of three phase induction motors*. [online] Electricaleasy.com. Available at: <<https://www.electrical4u.com/2014/02/starting-of-three-phase-induction-motors.html>>
- [5] Editor., 2019. *A brief introduction to common bus and line regeneration*. [online] Motioncontroltips.com. Available at: <<https://www.motioncontroltips.com/brief-introduction-common-bus-line-regeneration/>>
- [6] ElectGo. 2018. *Motor Protection #6 Methods to protect a motor from specialist*. [online] Available at: <<https://www.electgo.com/motor-protection/>>
- [7] Vfds.org. 2020. *Variable frequency drive Rectifier*. [online] Available at: <<http://www.vfds.org/variable-frequency-drive-rectifier-245010.html>>
- [9] Ppi-uk.com. 2019. *Thyristor Controlled Rectifiers*. [online] Available at: <<https://www.ppi-uk.com/news/thyristor-controlled-rectifiers/>>
- [10] Vfds.com. 2018. *Switching it up: IGBTs | VFDs.com*. [online] Available at: <[https://vfds.com/blog/switching-it-up-igbt#:~:text=An%20Insulated%20Gate%20Bipolar%20Transistor.VFD%20\(Variable%20Frequency%20Drive\).&text=An%20IGBT%20is%20the%20inverter,first%20developed%20in%20the%201980's.>](https://vfds.com/blog/switching-it-up-igbt#:~:text=An%20Insulated%20Gate%20Bipolar%20Transistor.VFD%20(Variable%20Frequency%20Drive).&text=An%20IGBT%20is%20the%20inverter,first%20developed%20in%20the%201980's.>)>

[11] Ecstuff4u.com. 2020. *ECSTUFF4U for Electronics Engineer*. [online] Available at: <<https://www.ecstuff4u.com/2018/05/difference-between-thyristor-and-diode.html>>

[12] Automate. 2021. *Understanding Power Factor and Harmonics*. [online] Available at: <<https://www.automate.org/industry-insights/understanding-power-factor-and-harmonics>>

[13] Electronic Tutorials. 2019. *Harmonics*. [online] Available at: <<https://www.electronics-tutorials.ws/accircuits/harmonics.html>>

[14] Pinyo, R., 2021. *Harmonics: Causes, Effects and Minimisation.*, [online] Salicru.com. Available at: <https://www.salicru.com/files/pagina/72/278/jn004a01_whitepaper-armonics_.pdf>