Adapting the Operation of Traditional Machining Workshop From 3 Phase 220 to 380 Volts 3 Phase and Rehabilitating the Machines: Case Study

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Abstract:

This investigation examined the migration of workplace equipment from a 3-phase 220 V power supply to a 3-phase 380V system. This shift needed exact modifications to the machines' electrical systems, including moving motor connections from the delta (Δ) to star (Y) concepts to meet the new voltage levels. Four center turning machines, one surface grinding machine, and one disc cutting machine were employed in modification within a conventional manufacturing environment. Approaches spanning circuit alterations, motor reconfiguration, and verification by electrical load evaluation were developed and followed methodically. The restoration project aimed to ensure that the equipment would extend operational life, improve energy efficiency, and suit the 380V supply. After changes, the project attained an operational rate of 100%. Power usage was considerably reduced from ineffective pre-adaptation levels with a reduction ratio of practically ≈52–64% current reduction; up to ≈17% active power reduction; PF improvement to 0.86. The results reveal that suitable reorganization of electrical motor connections, coupled with proper rehabilitating techniques, makes efficient operation of ancient Machinery inside current power systems possible, eliminating the need for expensive replacements. This paper presents the methods followed, obstacles encountered, solutions applied, and performance improvements noted as a pertinent case study for companies undergoing comparable transformation. The successful result was to run the machines on 3phase 380 instead of 3phase 220. Measuring the machines' current following change was discovered to be exactly one hundred percent less than the delta connections

Keywords: Motor 3phase 220- 380, Delta, Star, wire control, power, Maintenance.

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1. INTRODUCTION

The worldwide manufacturing sector always finds it difficult to adjust to changes in power availability, particularly when nations modernize their energy distribution systems. Many locations have replaced the older 3-phase 220 V power systems with more modern 3-phase 380 V systems compliant with international electrical standards (Lalitbhai, Patel et al. , Chapman 2003, Kalyan 2025, Singh 2025). This development drives the need to conserve energy, reduce transmission losses, and enable the system to run with more modern equipment that can withstand higher voltages (Martinich, Nagpal et al. , Hong, Huff et al. 2008, Kay and Padden 2020).

Three-phase induction motors run many Machines in workshops, particularly those involving building and mechanical engineering. Machinery, including disc cutters, center lathes, and grinding machines, still runs motors designed for the ancient 220 V three-phase power system. Should you link these devices to 380V power sources without making the required adjustments, the motors may become overly hot, the insulation may break down, the performance may suffer, or even the entire system may fail. Beyond basic technical adjustments, changing the operational settings of these devices is a crucial component of rehabilitation that guarantees they remain healthy, safe, and valuable for a long time (Eborall 1902, International Electrotechnical 2016).

The importance of the motor of the machine workshop includes electrical connections and adaptability. Changing the operation of workshop tools is essential for numerous purposes. Operational Safety IEEE Std

141-1993 states that the incorrect voltage may cause too much current, damage motor wiring and increasing the likelihood of fire occurrence. Equipment Lifetime: Appropriate adaptation increases tool lifetime, lowering replacement frequency and expense (Alciatore and Histand 2007, Gollhofer, Taube et al. 2012) From delta (Δ) to star (Y), switching wire kinds reduces phase voltage stress and increases the operating effectiveness (Ferreira, Ge et al. , Lei, Zhao et al. 2010, Patabo, Bijang et al. 2024). Particularly for large workshop machinery, fixing outdated machines is far less expensive than purchasing new ones. Adapting outdated equipment instead of purchasing new tools can save several hundred thousand dollars when an industrial environment requires dozens.

One can connect a 3-phase induction motor in a delta (Δ) or star (Y) arrangement. Delta (Δ) Connection: Every motor winding connects between two phases, so the motor runs on full line voltage. Designed for lower-voltage systems such as 220 V. Every motor winding connects between a phase and the neutral point, so each winding experiences a line voltage split by √3 (~58% of line voltage) (Ferreira 2008, Raja, Kumaresan et al. 2014).

Rewiring the motor in star configuration guarantees each winding only sees the suitable phase voltage (~220 V phase voltage from a 380V line voltage) when the system supply voltage increases (e.g., from 220 V to 380 V) and the motor windings are built for lower voltages. Phase voltage is line voltage divided by √3 (Dugan, McGranaghan et al. 1996, Gonen 2009, Atwa 2019, Ashayeri 2024). A 380V supply, therefore, produces a phase voltage of about 220 V, shielding the motor windings.

Every winding in a motor rated for 220 V (Δ connection) would encounter 380 V, which would cause instant overheating and damage if it were connected straight to 380 V (Δ). Adapting it to star (Y) will expose each winding to about 220 V. This alteration is highly advised and followed when updating workshops to new voltage standards (de Souza, Salotti et al. 2022, Márquez 2022, Wicklén 2024).

Although the equipment was designed for a 3-phase 220 V power supply, it was still operable. The challenge was to make these devices run safely and effectively under a 3-phase 380 V system. Modernizing the national grid, where distribution voltages were changed to the 400 V/230 V standard (Paul, Ormrod et al. 2014, Bishla, Neeraja et al. 2023, Mari, Bucci et al. 2024) required a power supply upgrade for the workshop**.**

In this study to machines adaptions there are several technological challenges such as identification of winding configuration. Many ancient machines lack complete schematics. Complicating adoption were degraded wiring, worn insulation, and rusty connectors in aging components. space restraints and rewiring problems brought on by tight machine interiors. Rigid testing was needed to ensure correct reconnection and to verify the absence of open or short circuits. Methods of electrical motor testing such as megger tester-based insulation resistance testing to ensure motor winding insulation remains effective. See suitable rewiring in continuity testing. Make sure the 3-phase system generates phase balance and balances voltage (Ferreira 2008, Antonino-Daviu 2020, Zheng 2022, Maiti 2023). For instance, counsel closely reading insulating resistance before any re-energizing activity.

2. EXPERIMENTAL WORK

This work mostly tries reconfiguring the motors from delta (Δ) to star (Y) connection to satisfy the new 380V system. During adaptation, fix and repair any insulation and wire flaws. To guarantee complete dependability, test the functioning capacity of every piece of equipment. Calculate and study variations in running performance and energy expenditure. Review suitable continuity testing rewiring. Check whether the created 3-phase system generates phase balance and balanced voltage. This work benefits practically and intellectually in the following respects, offers industrial workshops a detailed, methodical approach, Energy Saving.

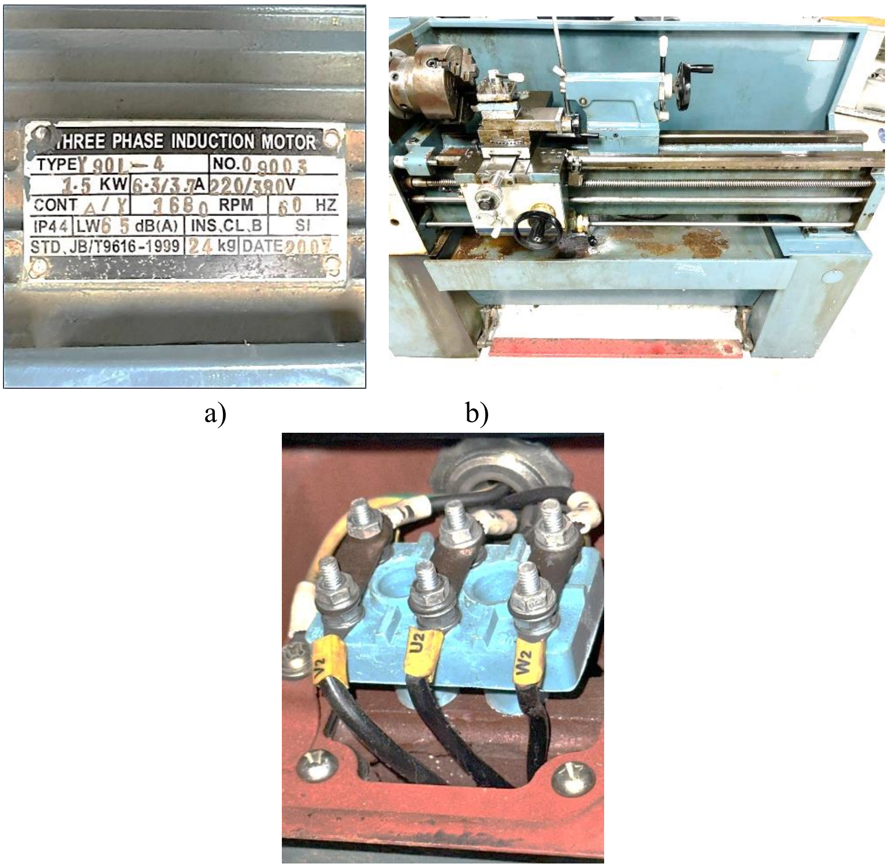
, encouraging the reuse and upgrading of current machinery replacements. Reducing operational and financial risks connected with voltage mismatches is a risk-mitigating action.

2.1 The adaptation process

Originally built to run on a three-phase, 220 V supply, all four center turning machines, one disc cutting machine, and one grinding machine in the machine shop were under inquiry. To guarantee operational integrity and safety, once the power infrastructure was upgraded to 3-phase 380 V, the motor wire configuration of these machines was changed from delta (Δ) to star (Y). The experimental methods, technical procedures, and rehabilitation process are described here.

2.1.1 Four center lathe machine machines:

Figure 1 shows that center lathe machines 1, 2, 3, and 4 are manual machines with a swing diameter of 500 mm, the distance between two centers is 1 m, and a motor with 1.5 kW of power. There will be a conversion from 3-phase 220 V to 3-phase 380 V for four machines Figure 1 shows the motor of specification before adaptation from 3phase 220 to 3phase 380.



a) b)

c)

Figure 1. a) Motor specification, b) Center lathe machine, c) Delta motor connection before

2.1.2 Grinding Machine:

We are adapting a 1.5 kW motor for a surface grinder machine. Figure 2 shows (a) the grinding machine and (b) the motor's specifications and delta wiring connections for 3-phase 220. As shown in the wiring diagram (c), the switch changes from 3-phase 220 to 3-phase 380, and the connections change from delta to star. This switch allows the motor to operate efficiently at different voltage levels by altering the wiring configuration, which is essential for ensuring compatibility with various power sources. The delta and star connections help optimize performance depending on the voltage supplied.

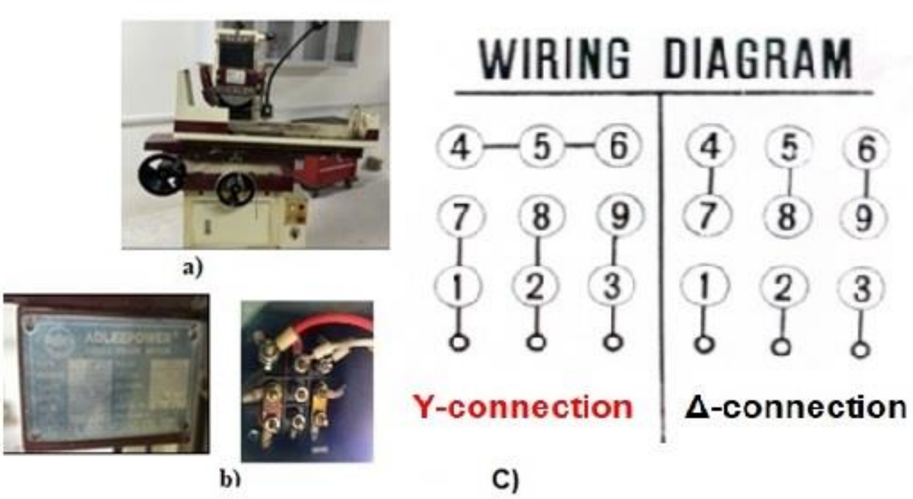


Figure 2. a) Grinding machine b) Motor specification c) Wiring diagram delta/star connection

2.1.3 Abrasive disc cutter:

Figure 3 provides the parameters for the 5.5 kW motor, which is what the disc cutting indicates. As Figure 4 shows, the technique changes from delta to star connections.

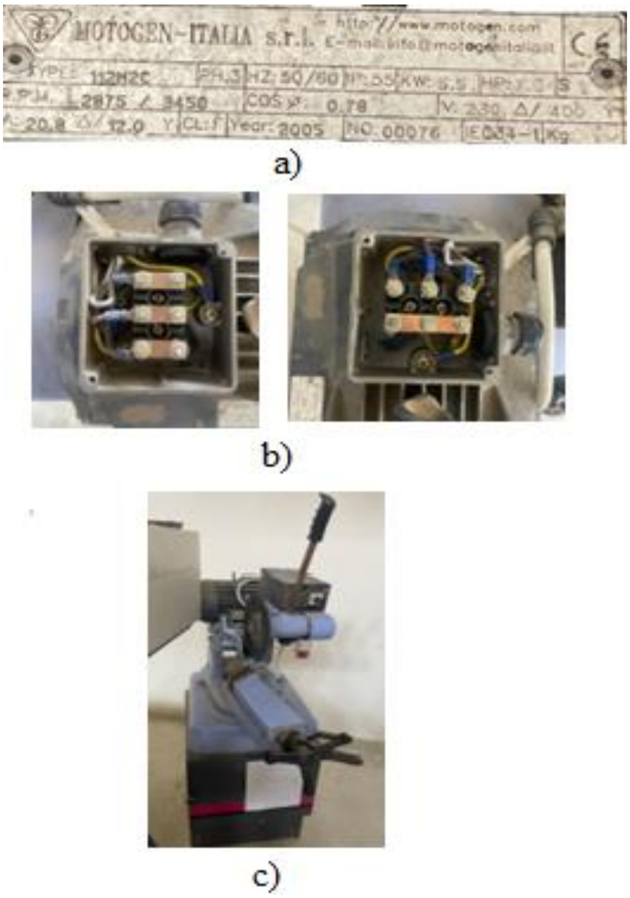


Figure 3. Disc Cutting a) Motor specifications and b) Delta and star motor connection c) Machine photography

2.1.4 Inspections of all motor connections

Measuring insulation resistance below established safety levels replacement for some of the brittle wire discovered in control panels was needed. A careful checklist was developed to ensure complete inspection of every piece of equipment (Márquez 2022)(Table 1).

Table 1. Data checklist of machine motors

Machine	Motor Rating	Initial Connection	Rewiring Needed?
Lathe 1,2,3,4	1.5 kW	Delta (Δ)	Yes
Grinder	1.5 kW	Delta (Δ)	Yes
Cutting disc	5.5 kW	Delta (Δ)	Yes

2.2. Methodologies of electrical rewiring

Six terminals for each of the start and finish of three stator windings (U1, V1, W1, U2, V2, W2) were found in most of the motors. Using continuity testing, digital multimeter (Fluke 117 model), the first step was to determine the start and finish of each winding properly (Sharifi and Ebrahimi 2011, Stone 2013, Sheikh, Bakhsh et al. 2022). Resistance measurement: To verify identical values over all three windings (~0.5–2 Ω usual). Note: Inaccurate identification of this could lead to immediate motor failure or a phase imbalance. To save change from delta (Δ) versus star (Y) delta connection original wiring delta connection. U1 attached to W2, V1 wired to U2, W1 linked to modified Star Connection V2. Connected to form the neutral points are U2, V2, W2.W1, V1, U1 coupled to the entering 3-phase power source.

The wiring technique must be turned off the motor first, Transparency motor terminal box. Specify U1, U2, V1, V2, W1, W2. Test insulating resistance and continuity. Reconnect W2, V2, and U2 all together as shown in Figure1. Connect L1, L2, and L3 independently from U1, V1, and W1 correspondingly. Heat-shrink tubing will insulate every joint. Close the terminal box and mark connections as shown in Figure .4.

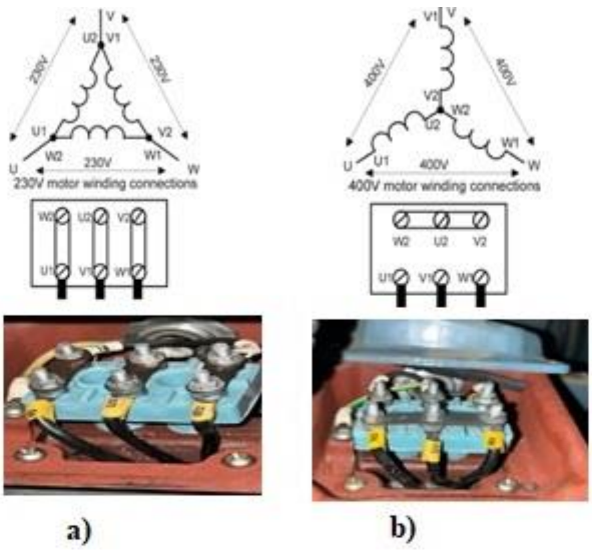


Figure 4. a) Delta (Δ) Configuration b) Star (Y) Configuration

2.3 Safety strategies

Lockout-tagout (LOTO) policies separated electrical supply throughout all operations.

Personal protective equipment (PPE) is required, including flame-resistant clothes, goggles, and insulating gloves. Oversaw all rewiring projects from a certified electrical standpoint.

Grounding tests carried out upon reconnection (Khawi and Asmary , Mutawe, Tsunehara et al. 2002).

2.4 Reconstruction and component replacement

Specific machines showed worn or fragile cabling within control panels, replaced with new heat-resistant cables rated at 600 V. New contactors designed for running 380 V. Overload relays replaced modified current values. Control wiring connection changing from 220 to 380 V as shown in Figure.5 for center lathe machines and Figure 6. For grinding machine.

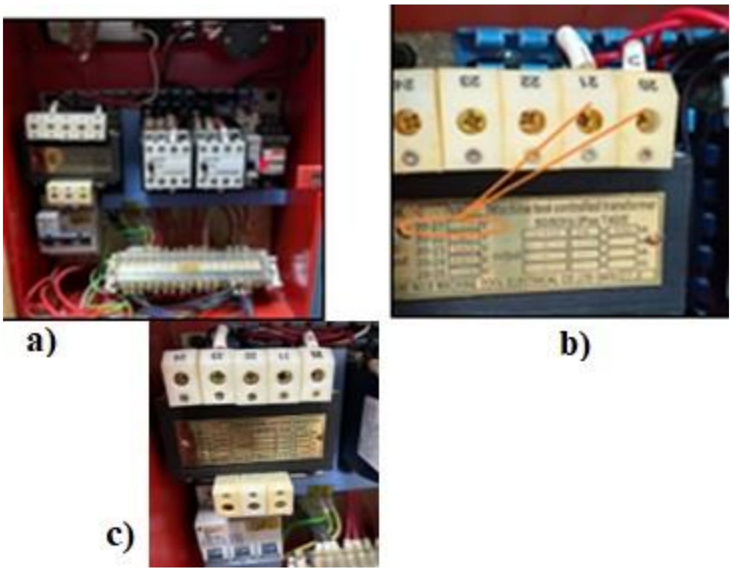


Figure 5. a, b) Control wire connection of the lathe 220 V   c) Control wire connection changing to 380V

Figure 6. a,) Control wire of grinding machine connection before   b) Control wire connection after

2.5 Process of functional testing

Functional testing was done for 30 minutes with no load and full load to check the temperature, vibration, and insulation quality of the motor. The insulation resistance, which was measured with a 1000 V Megger, was more than 20 MΩ, which shows that the winding is in great shape. The results in Section 2.8 show that switching to 380 V (Y-connection) made the motor's thermal balance much better and cut down on mechanical vibration.

2.6 Data recording and analysis

There was a complete record for each machine that included the motor nameplate data, the type of connection (before and after), the voltage, the current, and the power measurements. It is easy to find all the relevant standards and performance metrics for maintenance and fixing problems because there is so much documentation. Operators can make smart choices about how to run and improve machines by keeping such detailed records. The data recording as shown in Table 2 and Figure 7 were obtained with careful attention, applying the same settings for both no load and full load current before and after adaptations from 3-phase 220 to 3-phase 380. The analysis shows that there is a strong connection between the input parameters and the results of the performance. These results show that the recorded data is correct and support the main findings of this study.

Table 2. Recording data full load current before and after adaptation

Machine	No-Load Current Before (A)	Full Load Current Before (A)	Full Load Current After (A)	Changes %
Lathe 1,2,3,4	6.3	8	3.7	-53.75
Grinding machine	5.3	5.8	2.1	-63.7
Disc Cutting	20.8	25	12	-52

Figure 7. Measuring full load current after adaptation to 3phase 380 grinding machine

2.7 Calculations of power consumption

Verifying if the machines run more effectively under the increased voltage circumstances was one of the objectives of the adaptation. Measuring line current (A) under both idle and working loads, clamp-type ammeters. Actual line-to-true RMS voltmeters measured line voltage. Power meters logged real-time active power (kW), reactive power(kVAR), and Analysis: Operating current consistently dropped between 48 and 52 percent (De Almeida, Ferreira et al. , Saidur 2010, Fantidis 2015).

In summary, the alteration resulted in superior machine performance, reduced energy consumption, and increased longevity. This transformation renders it an exemplary option for industrial applications from both a technical and economic perspective as shown in Table 3.

2.8 Analysis of noise and vibrations

Mechanical problems in old machinery often cause too much noise and vibration. Following electrical adaptation, vibration testing was carried out with a digital vibration analyzer (Testo 890-2). Sound level checks were done with an EdTech 407730 sound meter. The acceptance criterion for RMS vibration is less than 5 mm/s. Sound pressure levels are less than 85 dB(A) one meter away (Tomlinson 1991, Ashnibha 2012). After the motor rewiring, noise levels remained the same Table 3 shows that the vibration levels were improved and still within reasonable limits for industry. The modified motors don't need any more dynamic balancing. This means that the changes made to the motors worked and didn't cause any new problems that would require further adjustments. In general, the results indicate that the rewiring process was successful.

2.9 Operational tune-through and calibration

Some machine controls still require fine-tuning upon adaptation: The lathe speed selections underwent recalibration. Where needed, coolant pumps running on auxiliary motors were rewired. Start/stop push buttons were tested with revised motor starters. Note that settings on motor protection changed load relay settings dropped by 30–35% to meet lower running currents following adaptation.

2.10 Troubleshooting difficulties

A few problems arose during adaptation, including unknown internal motor configurations: Some motors needed thorough diagnostic testing since they lacked legible labels. New heavy-duty ceramic terminals rated for 600 V/30 A replaced deteriorated terminal blocks. One grinder motor initially failed to start because of an improper star point connection; this was fixed during troubleshooting.

2.11 Economic and environmental influence

Through the adaptability and rehabilitation of these machines: waste reduction: Steered clear of scrapping over three tons of heavy machinery. Resource conservation: There is no need for new motors.

Cost reductions: the approximate savings as replacement costs calculated for four lathes are SR 120000; one grinder is around SR 40,000; and the cutting disc is SR 8,000. Overall, it exceeds 168,000.

Reduced current draw and improved power factor correction suggested yearly energy savings between 26 and 28 %.

3. RESULTS AND DISCUSSIONS

3.1 Synopsis of results from adaptation

On all chosen equipment—four center lathes, one grinding machine, and one disc cutter—adaptation of workshop machinery from 3-phase 220 V delta configuration to 3-phase 380 V star configuration was effective. Apart from allowing the machines to operate correctly at the new voltage level, the adjustment generated obvious advantages in running performance, energy efficiency, and equipment lifetime. Overall results showed the perfect success rate free of major machine defects or losses. Energy use usually dropped between 17 and 20%. Improved power factor by 26.5%. Levels of mechanical vibration somewhat dropped. After adaptation to the 380 V (Y-connection) arrangement, Table 3 illustrates the machine's electrical and mechanical performance parameters. The Table demonstrates how the power, current, vibration level, and temperature rise, changed before and after the alteration. These data illustrate that the change made stability and improving the performance that were measured at full load and no-load situations, operational stability is much improved.

Table 3. Measuring data before and after adaptation

Machine	Parameter	220V Delta	380V Star	Change (%)
Center Lathe machines	Current no load (A)	6.6 A	3.2 A	-51.5
Center lathe machine	Current full load(A)	8	3.7	-53.75
Center Lathe machines	Power Consumption (kW)	3.5 kW	2.9 kW	-17.1%
Grinding Machine	Motor Surface Temp (°C)	85 °C	68 °C	-20%
Grinding machine	Current full load (A)	5.8	2.1	-63%
Disc Cutting Machine	Vibration Level (mm/s)	4 mm/s	3.3 mm/s	-17.5%
Workshop Total	Power Factor (cos φ)	0.68	0.86	+ 26.5%

3.2 Electric performance both pre- and post-adaptation

Rewiring measurements showed significantly lower no-load and full-load currents. The average Reduction: No-load current: ~51% and Full-load Current: ~53.75%. The effective energy economy depends on power factors (PF). The PF values ranged from 0.66–0.75 before adaptation; values improved to 0.82–0.88 after adaptation. This suggests lower reactive power use from the supply grid, lower electrical energy waste, and better voltage stability throughout the internal workshop distribution network (Rachmadita, Rahman et al. 2024).

3.3 Evaluation of mechanical performance

Table 4 shows that monitoring the vibration after adaptation indicated a moderate decrease in motor vibrations. The drop in vibration from 13.31% to 23.6% is usually due to better motor starting characteristics (Patel, Bhalja et al. 2020). This improvement is crucial for enhancing the accuracy of machines, particularly in relation to the roughness of metal cutting. Such enhancements not only contribute to improved surface finishes but also extend the lifespan of cutting tools. As a result, manufacturers can achieve higher productivity and reduced operational expenses, allowing for more efficient production processes. This synergy between reduced vibrations and improved machine performance illustrates the value of continuous innovation in manufacturing technologies.

Table 4. Vibration measurement

Machine	Vibration Before (mm/s RMS)	After (mm/s RMS)	Reduction %
Lathe 1,2,3 and 4	4.73	4.1	13.31
Grinding Machine	3.6	2.75	23.6
Cutting Disc	4	3.3	17.5

Measuring noise also exposed some little improvement:

Before adaptation: 82–85 dB(A); after adaptation: 78–80 dB (A), with a small change, operator safety and workplace ergonomics get better (Güçlü, Ünsal et al.).

3.4 Thermal variability and dependability

Thermal imaging shows pre-adaptation motor casing temperatures between 70 and 85°C during full-load operation. Temperature of motor casing within the range of 50–68°C after adjustment. Low running temperatures indicate less possibility of motor insulation breakdown (Romo and Adrián 1998, Sousa, Hafner et al. 2012, Holst and Gregart Malmberg 2024). The designed motor lifetime is roughly thirty to forty percent longer.

Table 3 demonstrates that the line currents recorded for each lathe significantly lowered after adaptation to a 380V star connection. The decrease range shows lower electrical load and better motor efficiency: the reduction full load current and power motors are 40.5 ,62 and 17% respectively.

The Table shows that post-rehabilitation, the power factor rises from 0.68 to 0.86. Higher power factors derive from lower reactive power losses and better use of electrical energy.

Thermal Effect: The grinding machine clearly reduced the surface temperature from 85°C to 68°C in the Table. Lower running temperatures enhance the life of insulation and help improve motor durability. Measuring in Tables reflecting increased mechanical stability and operator safety, disc cutter vibration levels dropped by 17.5%.

3.5 Monetary effects

Whenever the machines switched from delta to star adaptation, they used less power, vibrated less, and got less hot, all of which helped them use less power when running continuously. The lower electrical losses and thermal stress meant less maintenance and longer component life.

Thus, the overall savings came from three main things:

1. Price replacement for all machines
2. Less electricity is used because the current balance and motor efficiency have improved.
3. Lower need for maintenance because there are less vibration and heat.
4. Less downtime because the system is more reliable and runs more smoothly.

These effects together led to measurable savings in operations and a shorter payback period for the adaptation. This indicates that the 380 V (Y-connection) conversion has both technical and economic benefits for older industrial machines.

The savings come from using less energy. The average power reduction is 0.7 kW, and the system runs for 8 hours a day, 300 days a year. This means that the system saves about 1680 kWh of energy each year, which is about 504 SR less than it would cost at a rate of 0.3 SR/kWh. The savings for one lathe are small, but for all the workshop machines, they add up to big savings in energy and money.

3.6 Broad success and learned skills

This experiment shows that changing out-of-date workshop equipment is a sensible and economical solution when the power infrastructure changes. Star connection at higher voltage allows smooth machine operation without compromising performance. Appropriate electrical safety practices are vital for effective machine rehabilitation. Correct identification of motor terminals and suitable rewiring methods can help to avoid equipment damage.

4. CONCLUSIONS

The adaptation effort detailed in this study demonstrated the possibility of converting present workshop machinery from a 3-phase 220 V delta system to a 3-phase 380 V star system. The workshop maintained its machines by stressing careful planning, accurate electrical connections, extensive safety testing, and performance validations—which matched new power supply conditions.

Among other targeted tools, four center lathes, a grinding machine, and a disc-cutting machine had methodically rewired their motor configurations from delta to star. The conversion was finished without the need for costly new equipment, saving significant financial savings of around 168,000 SR in avoided replacement expenses by themselves.

An important technological success of the study is the 52–63.5% drop in full-load electrical currents, which raises energy efficiency.

From 0.70 to 0.85, an average improvement in power factor results in enhanced grid use and reduced fines linked with low power factor operations.

Notable decreases in motor running temperatures and vibration levels suggest better mechanical dependability and longer equipment life spans; a little but noticeable reduction in workplace noise would improve operator comfort and ergonomics.

One important outcome was the knowledge that up to 17% of energy consumption might be lowered, saving thousands of Saudi riyals annually. The workshop also avoided creating several tons of trash machinery, supporting environmental sustainability goals.

The challenges were finding motor terminals, managing degraded terminal blocks, and confirming the correct phase sequence after rewiring. Overcoming these challenges was achieved by strict respect to industrial electrical safety rules, thorough inspection, appropriate testing tools including phase rotation meters and insulation resistance meters.

Effective adaptation underscored the need for careful planning, expert technical execution, and extensive testing when retrofitting old industrial machinery for new architectural circumstances.

Future ideas call for proactive, predictive maintenance techniques anchored on vibration and thermal imaging.

Training staff members in modified star-connection inspection methods.

Examining the possibilities to maximize energy use by adopting soft starts or Variable Frequency Drives (VFDs).

Ultimately, rehabilitation and conversion of workshop machines from 220 V delta to 380 V star operation provides a practical, safe, cost-effective, and ecologically responsible path for industrial facilities facing changes in their electrical supply networks. The methods applied in this work can serve as a manual for similar retrofitting projects conducted in various industrial settings.

Nomenclature	
V	Volt
kW	Kilowatt
PPE	Personal protective equipment
kVAR	Reactive Kilo volt ampere
VFDs	Variable Frequency Drives
SR	Saudi riyal
kWh	kilowatt-hour
RMS	Root mean square
LOTO	Lockout-tagout
IEEE	Institute of Electrical and Electronics Engineers (IEEE)

Data availability

All pertaining data to the current study are obtainable from the authors, who are willing to provide them on demand.

Author contributions

All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest

The authors state there is no conflict of interest.

Declarations of Interests

The author declares that no funds, grants, or other support were received during the preparation of this manuscript.

REFERENCES

Alciatore, D. G. and M. B. Histand (2007). Introduction to mechatronics and measurement systems, McGraw-Hill New York ISBN: 978-0-07-2963052.

Antonino-Daviu, J. (2020). "Electrical monitoring under transient conditions: A new paradigm in electric motors predictive maintenance." Applied Sciences 10(17): 6137. https://doi.org/10.3390/app10176137

Ashayeri, O. (2024). "Introduction, Maintenance and Repair of Electric Drives." https://urn.fi/URN:NBN:fi:amk-202405018648

Ashnibha, R. A. (2012). "An investigation into current and vibration signatures of three phase induction motors."

Atwa, O. S. E. (2019). *Practical power system and protective relays commissioning*. Academic Press.

https://doi.org/10.1016/C2018-0-00911-1.

Bishla, E. S., B. Neeraja, S. Chebiyyam and T. P. K. Gautam (2023). Fundamental Of Electrical Engineering And Applications, AG Publishing House. ISBN: 978-8119338436

Chapman, S. J. (2003). Electric machinery fundamentals, McGraw-Hill Education. ISBN: 978-0072465235

de Almeida, A. T., Ferreira, F. J. T. E., & Duarte, A. Q. (2014). *Technical and economical considerations on super high-efficiency three-phase motors*. IEEE Transactions on Industry Applications, 50(2), 1274–1285. https://doi.org/10.1109/tia.2013.2272548.

de Souza, D. F., Salotti, F. A. M., Sauer, I. L., Tatizawa, H., de Almeida, A. T., & Kanashiro, A. G. (2022). *A performance evaluation of three-phase induction electric motors between 1945 and 2020*. Energies, 15(6), 2002. https://doi.org/10.3390/en15062002

Dugan, R. C., McGranaghan, M. F., Santoso, S., & Beaty, H. W. (1996). *Electrical Power Systems Quality*. McGraw-Hill Interamericana. ISBN: 978-0780334649

Eborall, A. C. E. (1902). *Electrical driving of workshops and factories: Application of three-phase motors to the* (RSA Journal, Vol. 51, p. 464). Journal of the Royal Society of Arts

Fantidis, J. (2015). "The temperature measurement of the windings in a three-phase electrical motor under different conditions." Gazi University Journal of Science Part A: Engineering and Innovation 3(2): 39-44.

Ferreira, F. J. T. E. (2008). "Strategies to improve the performance of three-phase induction motor driven systems." https://edocs.tib.eu/files/e01mr17/1002518040.pdf

Ferreira, F. J. T. E., B. Ge, E. C. Quispe and A. T. De Almeida Star-and delta-connected windings tolerance to voltage unbalance in induction motors, IEEE. DOI: 10.1109/ICEM51905.2022.9910896

Gollhofer, A., W. Taube and J. B. Nielsen (2012). Routledge handbook of motor control and motor learning, Routledge New York, NY. ISBN: 978-0415669603

Gonen, T. (2009). Electrical power transmission system engineering: analysis and design, CRC press.

Güçlü, S., A. Ünsal and M. A. Ebeoğlu Vibration analysis of induction motors with unbalanced loads, IEEE. ttps://www.eleco.org.tr/openconf_2017/modules/request.php?a=Accept+as+Lecture&action=view.php&file=1%2F103.pdf&id=103&module=oc_proceedings&utm source.

Holst, L. and J. Gregart Malmberg (2024). "Induction Motor Voltage Dependence-How the consumption of Active power and Reactive power of 1-phase & 3-phase Induction Motors are affected by voltage dips." http://hdl.handle.net/20.500.12380/308524

Hong, S. S., P. A. Huff, P. C. Leach, R. S. Benfell, M. Gottliebson, S. H. Palac, E. W. Paschal, R. N. Skeehan, P. A. Trager and A. Vause (2008). Chapter 8 - Electrical Fundamentals and Power System Principles. Pumping Station Design (Third Edition). https://doi.org/10.1016/B978-185617513-5.50015-9

Kalyan, L. (2025). Essentials of Electrical Machines, Educohack Press. https://books.google.com.sa/books?hl=ar&lr=&id=y5lIEQAAQBAJ&oi

Kay, J. A. and L. K. Padden (2020). "Review of the new IEEE Std. 3004.8 "recommended practice for motor protection in industrial and commercial power systems" with focus on forest products industries." IEEE Transactions on Industry Applications 56(4): 3350-3358. https://doi.org/10.1109/TIA.2020.2986672

Khawi, H. A., and A. M. Asmary. 2024. "Digital Lockout/Tagout Tracking and Control System." Paper presented at the SPE International Health, Safety, Environment and Sustainability Conference and Exhibition. https://doi.org/10.2118/220455-MS.

Lei, Y., Z. Zhao, S. Wang, D. G. Dorrell and W. Xu (2010). "Design and analysis of star–delta hybrid windings for high-voltage induction motors." IEEE Transactions on Industrial Electronics 58(9): 3758-3767. DOI: 10.1109/TIE.2010.2054058.

Mari, S., G. Bucci, F. Ciancetta, E. Fiorucci and A. Fioravanti (2024). "Impact of measurement uncertainty on fault diagnosis systems: A case study on electrical faults in induction motors." Sensors 24(16): 5263. https://doi.org/10.3390/s24165263

Márquez, A. C. (2022). Digital maintenance management, Springer. https://link.springer.com/book/10.1007/978-3-030-97660-6?

Martinich, T. G., Nagpal, M., Bimbhra, A., & Ramamurthy, M. (2012). *Hazardous Temporary Overvoltages from Self-Excited Large Induction Motors — A Case Study*. DOI: 10.1109/TPWRD.2012.2206616

Mutawe, A. M., R. Tsunehara and L. A. Glaspey (2002). "OSHA'S lockout/tagout standards: a review of key requirements." Professional safety 47(2): 20. https://aeasseincludes.assp.org/professionalsafety/pastissues/047/02/023668de.pdf?

Patabo, M., H. Bijang, D. Kantohe, W. Enoch, J. Najoan and H. Sibuea (2024). "Design of star delta control circuit work system on 3 phase electric motor." Jurnal Impresi Indonesia 3(5): 391-397. https://doi.org/10.58344/jii.v3i5.4854

Patel, R. A., B. Bhalja and M. A. Alam (2020). Condition Monitoring of Three-Phase Induction Motor. 2020 IEEE 1st International Conference for Convergence in Engineering (ICCE). https://doi.org/10.1109/ICCE50343.2020.9290540

Paul, D. L., Ormrod, J. E., & Johnson, L. R. (2014). *Practical research: Planning and design* (11th ed.). Pearson Education. ISBN 978-0132946601

Rachmadita, R. N., F. W. N. Rahman, E. Setiawan, A. I. Juniani, W. Wiediartini and L. J. Satrianata (2024). "Energy Saving Opportunities in 3-Phase Induction Motors with Variable Speed Drive (VSD) Drives." Jurnal Teknik Elektro dan Komputer TRIAC 11(2): 51-57. https://doi.org/10.21107/triac.v11i2.26971

Raja, P., N. Kumaresan and M. Subbiah (2014). "An improved delta-star switching scheme for reactive power saving in three-phase induction motors." Frontiers in Energy 8(3): 364-370. https://doi.org/10.1007/s11708-014-0324-8

Romo, J. L. and M. B. Adrián (1998). "Prediction of internal temperature in three-phase induction motors with electronic speed control." Electric power systems research 45(2): 91-99. https://doi.org/10.1016/S0378-7796(97)01189-9

Saidur, R. (2010). "A review on electrical motors energy use and energy savings." Renewable and Sustainable Energy Reviews 14(3): 877-898. https://doi.org/10.1016/j.rser.2009.10.018

Sharifi, R. and M. Ebrahimi (2011). "Detection of stator winding faults in induction motors using three-phase current monitoring." ISA transactions 50(1): 14-20. https://doi.org/10.1016/j.isatra.2010.10.002

Sheikh, M. A., S. T. Bakhsh, M. Irfan, N. b. M. Nor and G. Nowakowski (2022). "A review to diagnose faults related to three-phase industrial induction motors." Journal of Failure Analysis and prevention 22(4): 1546-1557. https://doi.org/10.1007/s11668%E2%80%91022%E2%80%9101445%E2%80%912

Singh, V. (2025). "Performance Optimization of Low-Cost DC Motors for Educational Engineering Applications." Journal of Engineering and Science 4(1): 56-66. https://doi.org/10.56347/jes.v4i1.270.

Sousa, K. d. M., A. A. Hafner, H. J. Kalinowski and J. C. C. d. Silva (2012). "Determination of Temperature Dynamics and Mechanical and Stator Losses Relationships in a Three-Phase Induction Motor Using Fiber Bragg Grating Sensors." IEEE Sensors Journal 12(10): 3054-3061. DOI: 10.1109/JSEN.2012.2210203

Stone, G. C. (2013). "Condition monitoring and diagnostics of motor and stator windings–A review." IEEE Transactions on Dielectrics and Electrical Insulation 20(6): 2073-2080. DOI: 10.1109/TDEI.2013.6678855

Tomlinson, J. N. (1991). Investigations toward predictive maintenance of mine electrical AC motors through vibration monitoring, The Pennsylvania State University. https://www.proquest.com/openview/57f78f8a77d43edb2472d68fadc2a115/1?pq-origsite=gscholar&cbl=18750&diss=y

Wicklén, E. (2024). "Analysis of the Environmental Impacts of Low Voltage Cast Iron Induction Motor: case study for ABB Motors R&D." https://urn.fi/URN:NBN:fi:amk-2024052415526

Zheng, Y. (2022). "Energy efficiency movement, policy impact and market transformation in electrical motor industry: Empirical study on Eco-design regulation adoption in ABB IEC Low Voltage Motor." https://urn.fi/URN:NBN:fi-fe2022120569357