Dated: 17-03-2022

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Title

In Pakistan's industrial sector, energy conservation is achieved through motors; therefore, energy efficient motors are required.

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Dated: 17-03-2022

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ABSTRACT

Pakistan has an energy shortage. The objective of this report is to shed light on Pakistan's current electrical power preservation attempts and the potential for electrical energy rescue in various sectors. This report also describes the consumption of energy-efficient motor technology solutions for commercial operations because motor load consumes 30%–70% of electricity. Various nations employ their norms, standards, and regulations to save power voluntarily or mandatorily, yet Pakistan lags.

1. INTRODUCTION

World warming, fossil fuel depletion, and the rise of a new world economy are all complicating the globe's energy picture, resulting in rising energy product values and financial instability for society. Figure 1 depicts the amount of oil and gas output and needed, with the ascending line indicating that the requirement is upward.

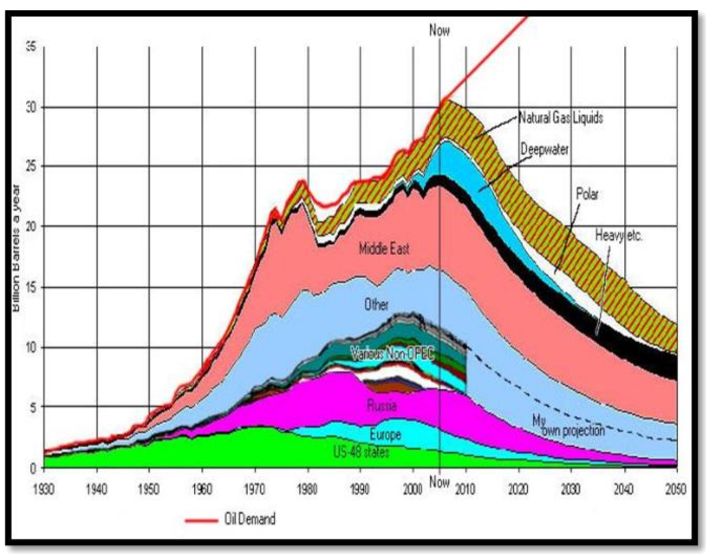

Fig 1: Development and demand for oil and gas around the world

The effect of increasing oil costs on Pakistan's economic activities is constantly contested; unrefined oil rates rose from 33 US dollars in January 2009 to 120 US dollars [1]. Raising oil prices causes high inflation, a major budget imbalance, and a slowing of international currency values, making imports more costly and, eventually, affecting power production. Because the commercial sector utilizes a huge quantity of electricity in motors, effective energy utilization will play an essential role in reducing energy use and emissions into the climate. Energy-efficient motors are typically 4-5 percent more efficient than standard motors; thus, increasing the energy efficiency of motors in the industrial sector will result in long-term growth for any economy.

2. PAKISTAN'S ENERGY CONDITIONS

Pakistan's overall total energy shortage began in FY 2007 and worsened from FY 2008 to FY 2011. Figure 02 shows that the energy to provide imbalance was obtained at 5000 MW. This prolonged power outage, lasting more than 12 hours a day in rural regions and 6–8 hours in urban areas, has had a severe influence on economic growth, holding industries off or reducing their output levels, affecting joblessness and employee earnings [2]

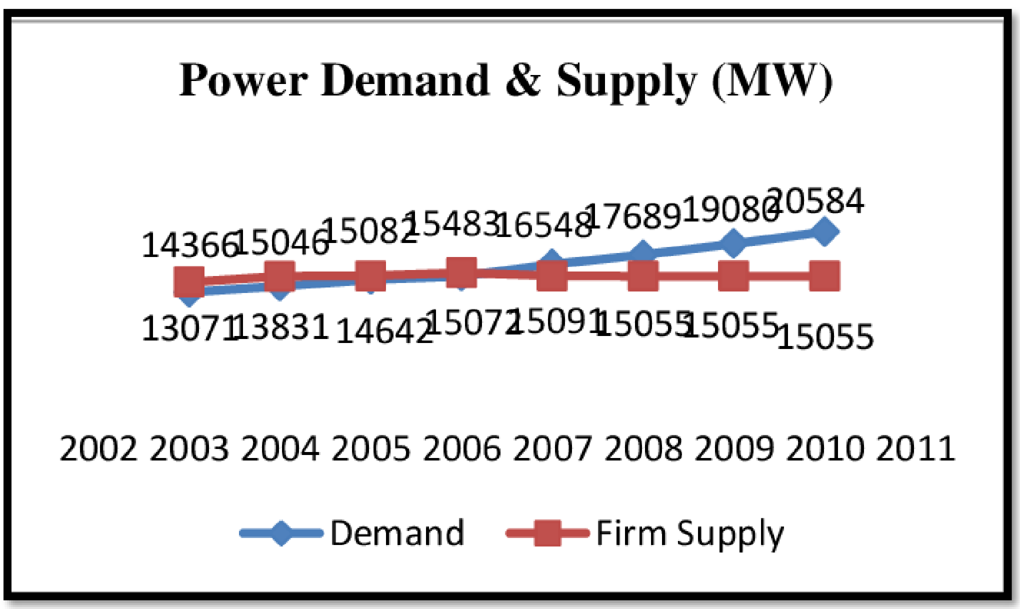

Fig 2: Power supply and requirements

In 2012, the Pakistani authorities are attempting to address the problem through a variety of initiatives, although energy efficiency has also been highlighted as an efficient instrument for immediate and moderate economic progress.

2.1.Pakistan's energy consumption by sector

Figure 03 depicts Pakistan's energy utilization; as can be observed, the commercial sector is the largest user of energy, which comprises oil, gas, and power generation [3]

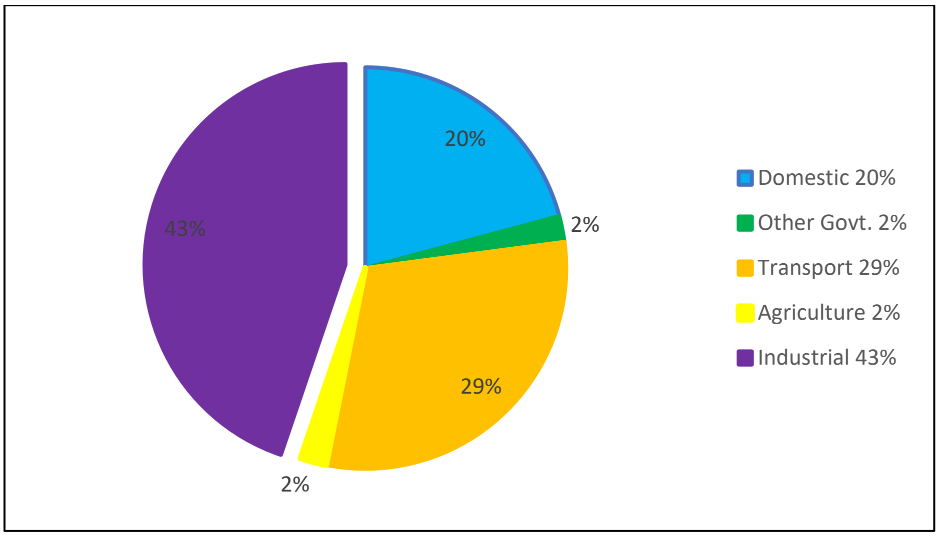

Fig 3: Energy usage is broken down per sector.

2.2.Pakistan's electricity usage by industry

Chart 04 depicts electricity utilization by industry. As can be seen from the figure, the industry sector is Pakistan's second-largest user of power, accounting for 27.5 percent of total expenditure, while agriculture accounts for 12.5 percent. Electricity motors account for around 30% to 80% of the load in these sectors; in industrial, they are utilized for various spinning machinery for processes, such as pumping, compressors, and fans, whereas in agricultural, they are utilized for motor-pump electrical motors [4].

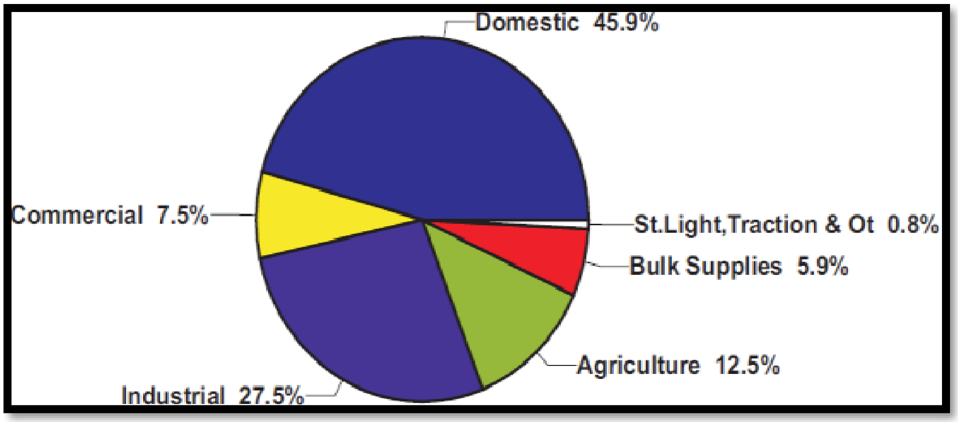

Fig 4: Electricity usage is broken down per sector.

The industrial sector is the largest energy consumer, accounting for 43 percent of total energy consumption, while the commercial sector is the second-largest energy producer, accounting for 27.5 percent of total electricity consumption. They only accounted for 19% of GDP in FY 2008 due to ineffective technologies and deteriorating infrastructure (ADB). Lower energy production has an impact on industrial performance.

According to the Asian Development Board report, Pakistan's electricity protecting potential in the industrial sector is predicted to be 11.2 percent for the ten-year expected period from 2009 to 2019, with an investment of 1850 million US dollars, and massive energy improvement improvements are seen in the textile, iron, steel, and sugar industries, as shown in Table 1 [3].

Malaysia has 48%, the United Kingdom has 50%, the United States has 75%, India has 70%, Turkey and the EU have 65%, Jordan has 31%, and Canada has 3%. Motors account for 80% of global industrial power consumption [5]. According to the International Energy Agency's proposed work plan for energy efficiency policy opportunities for electric motor-driven systems, about 15 TWh/year is consumed in Pakistan's major sectors, including industry, agriculture, residential, and transportation, accounting for about 38.3 percent of the country's total electricity demand [6].

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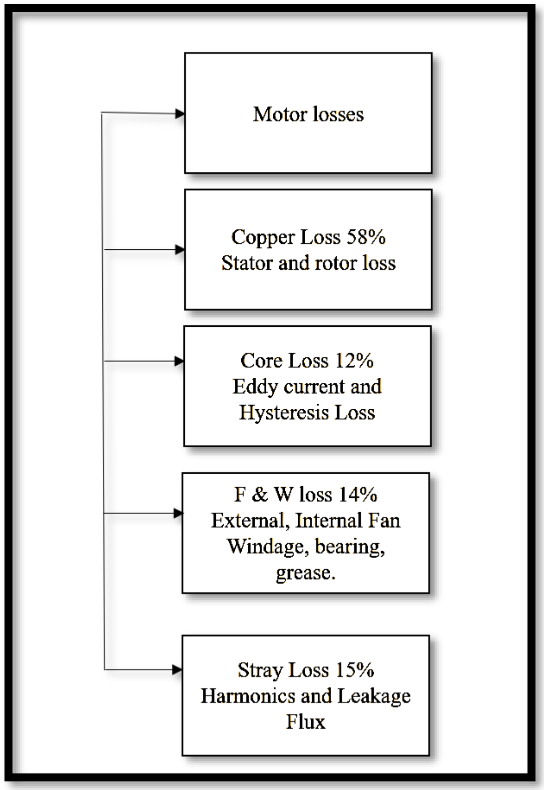

Fig 5: Technical motors losses

Table 1. electricity usage, achievable savings, and investment requirements in the industry.

Electricity Forecast		**Iron and Steel**	**Paper**	**Textile**	**Sugar**	**Other Industries**
Electricity Consumed FY 2008 (GW)		2704	572	5318	150	11985
Electricity Consumption Forecast FY 2019 (GW)		5475	1157	10768	304	24267
Electricity Consumption Forecast, FY 2019 (GW)	Technical	12	0	7	0	10
	Realizable	50	0	50	0	35
	Effective	6	0	4	0	3

Realizable Savings FY 2019 (GW)	166	--	186	--	817
Investment Required $ million	17	--	42	--	183
Simple Payback (yrs.)	1.3	--	2.9	--	2.9

Table 2. Three-phase induction motors have various efficiency criteria.

2 Pole			**4 Pole**		
kW	**Efficiency %**		**kW**	**Efficiency %**	
	Eff 1 or Above (High)	**Eff 2/Eff 3 (standard)**		**Eff 1 or Above (High)**	**Eff 2/Eff 3 (standard)**
1.1	82.8	76.2	1.1	83.8	76.2
1.5	84.1	78.5	1.5	85.0	78.5
2.2	85.6	810	2.2	86.4	81.0
3.0	86.7	82.6	3.0	87.4	82.6
4.0	87.6	84.2	4.0	88.3	84.2
5.5	88.6	85.7	5.5	89.2	85.7
7.5	89.5	87.0	7.5	90.1	87.0
11	90.5	88.4	11	91.0	88.4
15	91.3	89.4	15	91.8	89.4
18.5	91.8	90.0	18.5	92.2	90.0
22	92.2	90.5	22	92.6	90.5
30	92.9	91.4	30	93.2	91.4
37	93.3	92.0	37	93.6	92.0
45	93.7	92.5	45	93.9	92.5
55	94.0	93.0	55	94.2	93.0
75	94.6	93.6	75	94.7	93.6
90	95.0	93.9	90	95.0	93.9

3. LOSSES IN MOTORS

Electrical motor energy analyses and losses are obtained from specialist research, and methods to decrease them are also discussed [7] [8]. The losses that arise in the conventional kinds of motors previously utilized are depicted in Figure 05. A few years ago, the objective of the manufacturer was to make a motor that was less expensive to develop, so they used low-grade components and offered lower performance, but now the goal is to utilize high-grade elements to minimize the cost of power over the motor's lifetime.

The most generally utilized production procedures include the usage of high-grade materials and other parameters to decrease losses. Therefore, motors are classified as ordinary motors, high-efficiency motors, energy-efficient motors, and premium motors. The losses listed below were discovered through specialist research [7] [8], and [9].

4. ENERGY SAVING MOTOR

Because of improved design, manufacturing, and material procedures, energy-efficient motors may perform more work per unit of power utilization. A motor that is energy-effective has

- Excellent magnetic properties
- The space between the rotor and the stator has been narrowed.
- High-laminated stator winding
- Reducing heating and cooling losses
- Better insulation.

4.1. Efficiency provisions for standard and energy-efficient motors

Motor Performance Labeling Mechanism Table 2 [10] by Brooks Crompton displays the various performance clauses of triple-phase inductive motors.

5. ENERGY EFFICIENCY OPTION AND MOTOR SYSTEM

The idea of energy efficiency was imposed by research such as [11] [12] [13] [9]. Through the technique of electricity efficiency, one can say that a manufacturer or procedure is energy effective, particularly in comparison to another. The performance of motors is basically to be matched with new technological advancements presented or new motors with high reliability and produced warranties.

5.1.Policy on energy efficiency

Though a few organizations such as ADB, NPO, ENERCON, AEDB, and others are operating on energy efficiency and preservation programs, energy consumption in various processes or factories is not generally observed. According to Pakistan's performance control and uniformity responsibility, the standard for motors is PS IEC: 60034/2007 (Part 1 to 4), but there is no practical implementation of this standard, and there are no rules and regulations on this subject.

5.2.Energy consumption and savings of cross-country motors

Brazil According to specialized research, the commercial industry consumes 30% to 40% of global electricity, and electronic motors consume 30% to 70% of total power consumed by nations. Several advanced and developing countries, including Brazil, Malaysia, Canada, America, China, India, and others, are involved in energy preservation projects; Table 3 shows the agreements reached by various countries [14].

Garcia et al in 2006, used 9,000 industrial motors in Brazil to estimate capital expense and dollar savings by analyzing the energy efficiency of electric power motors and trying to replace them with energy-efficient motors. He found that industrial motors consume 121 T Saidur et al. Wh per year and that energy savings and dollar savings for the Brazilian country can be estimated at 1621GWh per year, with yearly expenses of 37 million US dollars [15].

Saidur et al in 2010, conducted scenario research for Malaysian industry's motors, claiming that if standard motors are inefficient and are replaced with high-efficiency motors, 1575GWh of energy can be saved for all categories of motors in 2010, resulting in a 105 million US dollar reduction in utility bills for the identical duration of time [16]

De Almeida et al in October 2001, a report published manufacturing or importing three-phase induction motors with a power range of 0.37KW to 185KW must meet MEPS requirements in Australia. Australia had a 10% premium performance share, 32% high-efficiency share, and 58% basic efficiency share of motors in 2005 [17].

6. MATHEMATICAL FORMULAS

To operate on effective motors, first, determine their present efficiencies. To do so, a few electrical parameters such as IR (real measured current), IN (nominal current) from the manufacturer, and Io (no-load present from the manufacturer or measured) must be determined.

$$\gamma = 1 + (1/\alpha) * Ln (IR/IN) \quad (1)$$

Load current parameter is measured by

$$\alpha = - Ln (Io / IN) \quad (2)$$

Io = no-load current

I_N = nominal current

The electrical efficiency of different components is calculated by power output to power input

$$\eta = P_{out} / P_{in} = (0.746 * PHP * \gamma) / PR \quad (3)$$

P_R = measured input power

P_{HP} = output power

γ = rated load (%)

η_L= exiting motor's efficiency

The IEE factor is the energy efficiency tells, percent of energy saved by replacement with new energy-efficient motor, given by:

$$IEE = (1 – \eta L / \eta) * 100 \% \quad (4)$$

6.1.Motors investment value (MIV)

The cost of a motor is the cost of the motor plus the cost of installation. High-efficiency motors are roughly 20% more costly than standard motors because they utilize more copper and other mechanical factors to boost efficiency. The high cost of new high-efficiency motors is a competing aspect in the business.

6.2. Energy conservation (kWh)

The electrical unit conserved is the energy conserved quantity. QES is used to calculate the amount of energy conserved per year by comparing standard motor performance to new motor productivity and motor operating hours to real loading rates.

$$QES = 0.746 * PHP * \gamma * t * (\eta L - 1/ \eta) \qquad (5)$$

6.3. Values of energy saved (in Rs.)

The quantity of energy conserved is calculated by multiplying the energy unit saved by the tariff per kWh. Because the expense of power varies depending on peak and off-peak requirements, a motor with the same rating working at the identical time will use the same unit but provide distinct results. The cost for the B3 commercial category is collected from HESCO in this study. The preceding equation gives the annual energy savings:

$$ESV = QES * C \text{ (Rupees / Year)} \qquad (6)$$

Table 03. Motor efficiency voluntary agreement and regulation around the world [15]

Country/ Region	Mandatory agreement (Year of Implementation)	Voluntary Agreements (Years of Implementations)
USA	EPAct-high efficiency (1997) NEMA Premium (2011)	NEMA Premium (2001)
Canada	EPAct level high efficiency (1997) EPAct level high efficiency (1998)	NEMA Premium (2001)

Mexico	EPAct level high efficiency (1998)	NEMA Premium (2001)
EU	-	Efficiency Classification and market reduction of Eff3 (1998)
Australia	High Efficiency (2006)	Premium Efficiency (2006)
New Zealand	High Efficiency (2006)	Premium Efficiency (2006)
Brazil	Standard Efficiency (2002) High Efficiency (2009)	High Efficiency
China	Standard Efficiency (2002) High Efficiency (2011)	Premium Efficiency (2007)
Korea	Standard Efficiency (2008)	Premium Efficiency (1996)

6.4.Repayment term

The payback time specifies when the amount spent will be repaid; establishing a new energy-efficient motor is expensive, hence a significant sum of cash will be committed. The MIV and ESV, which are supplied by the following equation, may be used to determine the payback or simple return.

$$SPB = MIV / ESV \text{ (yr)} \qquad (7)$$

7. MOTOR TECHNICAL INFORMATION

The 180 motors used in this study are 7.5 kW, 11 kW, 15 kW, 18 kW, and 22 kW three-phase inductive motors that are all 10 years old and have a total running duration of 8760 hours. The Fluke energy analyzer meter analyzed nominal power, nominal power with no-load current, and real power. According to the Hyderabad Electric Supply Corporation (HESCO) in May 2011, the cost of power per unit for B3 type connections is Rs 10/kWh.

Table 04. Three-phase induction motors data from standard motors

Power rated (kW)	**Motors**	**Nominal current (amp)**	**No Load Current (amp)**	**Current measured (amp)**	**Power measured (kW)**
7.5	**M1**	12.7	6.49	12	7.8
7.5	**M2**	12.7	7	11	6.72
7.5	**M3**	12.7	6.59	11.5	7.2
7.5	**M4**	12.7	6.49	11.3	7.1
11	**M5**	20.8	8.5	13.27	6.44
11	**M6**	19	8.5	17.2	11.21
11	**M7**	23	8.5	15.57	7.83
11	**M8**	19	8.5	11.8	6.36
15	**M9**	24.5	9	16.37	10.11
15	**M10**	24.5	9	16.17	9.9
18.5	**M11**	33.3	13	19.67	9.3
18.5	**M12**	33.3	13.1	21.17	10.8
22	**M13**	38	14	21.83	11.27
22	**M14**	38	13.5	22.6	12.45
22	**M15**	38	14.2	21.85	11.21

Table 5 illustrates the author's calculations and new efficiency derived from the European Union standard for energy efficiency policy possibilities.

Table 5. Calculation of the efficiency of a typical motor

Motors	LF (%)	Post (kW)	Pin (kW)	Measured Eff (%)	New Eff (%)
M1	0.9	6.75	7.8	0.865	0.905
M2	0.78	5.82	6.72	0.866	0.905
M3	0.84	6.33	7.2	0.879	0.905
M4	0.82	6.16	7.1	0.86	0.905
M5	0.49	5.56	6.44	0.86	0.918
M6	0.87	9.8	11.21	0.87	0.918
M7	0.6	6.8	7.83	0.86	0.918
M8	0.48	5.4	6.36	0.85	0.918
M9	0.59	8.9	10.1	0.88	0.923
M10	0.5	8.7	9.9	0.88	0.923
M11	0.4	8.21	9.3	0.88	0.926
M12	0.51	9.59	10.84	0.88	0.926
M13	0.44	9.95	11.27	0.883	0.928
M14	0.49	11.14	12.45	0.894	0.928
M15	0.43	9.79	11.12	0.87	0.928

The efficiency of the present motor is quite poor, as shown in the table above, while the new performance is calculated using the operator's chart for motor-driven systems (paul-waide with international energy agency 2011). When old motors are replaced with energy-efficient ones, it not only saves power units and rupees but also improves the performance of the machine, as shown in table 6. Figure 6 and Table 7 show the total energy savings in motors, as well as a comparison of motor investment and energy savings.

Table 6. Energy-saving and pay back

Motors	QES (kW)	ESV (Rs)	MIV (Rs)	SPB (Years)
M1	2991	29910	80000	2.6
M2	2475	24751	80000	3.2
M3	1787	17872	80000	4.4
M4	2549	25494	80000	3.1
M5	3263	32632	125000	3.8
M6	4631	46317	125000	2.6
M7	3661	36619	125000	3.4
M8	3652	36526	125000	3.4
M9	3975	39757	150000	3.7
M10	3874	38743	150000	3.8
M11	3786	37867	200000	5.2
M12	4190	41904	225000	4.7
M13	4739	47395	225000	4.7
M14	3878	38789	225000	5.8
M15	4918	49189	225000	4.5

Table 7. Electricity consumed, saving and payback from highly efficient motor

Electricity Consumed (MWh/year)	Electricity Saved (MWh/ Year)	MIV (Million Rs.)	Payback (Years)
3800	150	6.47	4.5

Figure 6 represents the motor investment value purchased from the market versus rupees saving by replacing the standard motor with energy efficient one

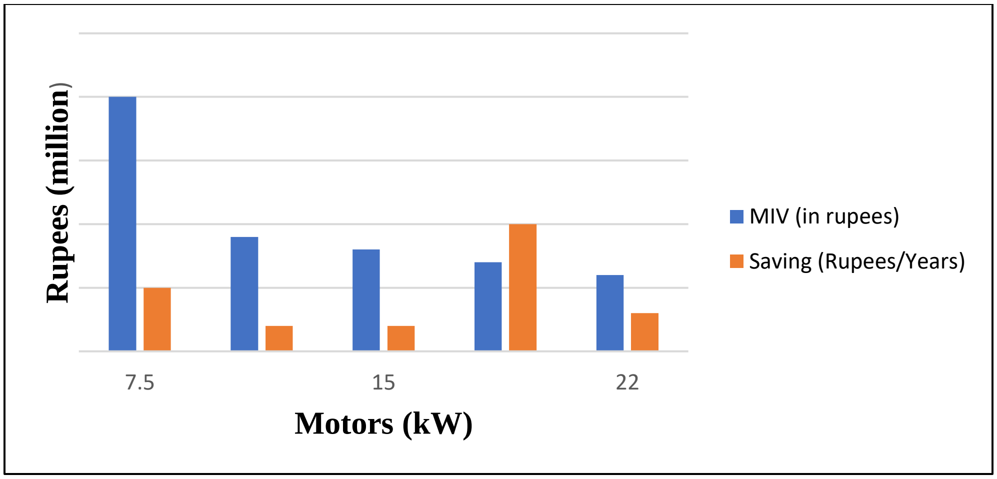

Figure 06. Motors investment versus saving in Rupees

8. ENERGY EFFICIENCY OF MOTORS

The following are various approaches to increase the entire industrial sector's efficiency by minimizing electrical energy waste from motors using energy-saving strategies.

8.1. Putting Regulation to Work

8.1.1. Approaches (mandatory/regulatory and voluntary)

Compulsory and regulatory procedures raise public and private sector knowledge that a specified level of MEPS (minimum energy performance standard) has been attained nationwide. By implementing required measures, an organization's and policymakers' image is promoted, which in turn minimizes energy needs and CO_2 emission components. It is important that, in addition to establishing a minimum performance level, voluntary methods for improving awareness and improvement are implemented. Furthermore, mandatory, or regulatory measures can be classified as MEPs, Enforcement, Certification, and Testing, whereas voluntary approaches can be classified as MEPs, Enforcement, Certification, and Testing (Labels, training, and tools, public procurement programs).

Energy Policy Act of the USA (EPACT-1992)

The United States made it mandatory in October 1997 for electrical motors, whether manufactured or imported, to satisfy minimal energy efficiency quality standards. In 2009, EPACT motors accounted for around 54% of the market share for motors.

NEMA – Premium (2002)

As many companies and industry groups were supporting higher efficiency motors than the EPACT level, the National Electric Manufacturing Association (NEMA) proposed a premium for higher efficiency motors plan. In 2005, NEMA premium motors had a market share of 16%, and the United States agreed that by 2011, the NEMA premium level should be upgraded to the minimum energy performance standard for electrical motors.

Mexico, Brazil, and Canada

Mexico Brazil is trying to improve motor standardization and has its own MEPs system. Mexico is currently following NOM-016-ENERB 2002, which matches the productivity of the same EPAct index. As of EPAct, Mexico's standard has a little broader application, as it only covers motors with a power range of 0.746KW to 373 KW. The EPAct employs 50/60Hz dual-frequency electric motors, whereas the Canadian Standard Association utilizes 50/60Hz dual-frequency electric motors.

EU (Europe and Pakistan)

The EU-CEMPS is a system for evaluating and identifying the effectiveness of motors. Eff 1 motors have a high index, Eff 2 motors have an efficiency value between low and high, and Eff 3 motors have a low-efficiency rating. 23 countries including Pakistan, have accepted this standard.

8.1.2. Incentives

The government should assist organizations and manufacturers by lowering taxes on items that are purchased or imported. The government and R&D offer financing, free audits, and investment rebates.

8.1.3. Application of technology

The organization must be aware of the need for auditing and employing appropriate technologies to reduce electricity use by installing VSDs, PF improvements, or new HEM motors.

9. CONCLUSION

In a country like Pakistan, where motors are used in the industrial and agricultural sectors, they are old, re-winded, and inefficient owing to their low initial cost. If these sectors were inspected, a significant amount of electricity could be conserved. It is recommended that the government promote and implement energy audits, energy efficiency, and conservation initiatives so that voluntary or compulsory action can be taken to boost the industrial sector's competitiveness and close the supply-demand gap.

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