International Journal of Innovations in Engineering and Technology (IJIET)
http://dx.doi.org/10.21172/ijiet.134.19

Electric Prime Mover: A need for smallholders in India

S P Singh[1], Utpal Ekka[2], Mukesh Kumar Singh[3], H S Pandey[4]
[1,2]Division of Agricultural Engineering, ICAR-IARI, New Delhi , India
[3,4]Agricultural Mechanization Division, ICAR-CIAE, Bhopal, India,
Presently Research Scholar at CTAE, MPUAT, Udaipur

Abstract- This paper described the possibility of the electric prime mover use in different farm operations for small farm holders in India that can be applied to minimize dependency of fossil fuels and increase the use of sustainable energy. The mechanical power source has been adopted in farm operations, due to its higher efficiency which primarily run on fossil fuels. Use of fossil fuel increases the CO2 emissions which has adverse effect on environment. Electric power is gaining importance due to its better efficiency and less impact on environment. It has become an option for the reduction of greenhouse gas emissions, mainly due to the advent of batteries. Further minimizes these emissions even more, if renewable energy such as solar is being used to charge the batteries. The DC/BLDC motor with stored electric energy, i.e. batteries can be used for mobile and stationary farm operations. Field operations with 350W DC motor of a walk behind farm equipment for sowing, weeding and cutting encourages to adopt electric prime mover for various other unit operations in the farm. The sowing, weeding and cutting operations with 250 to 350W brushed DC motor increased efficiency and helped in reducing drudgery of human beings significantly. Based on this study, 1kW BLDC motor size will be optimum for mobile and stationary farm operations (the equipment operated by human and animal source of power) for small farm holders (up to 1 ha). Solar photovoltaic cell can be successfully utilized for battery charging and can also be directly utilized for stationary operations. Moreover, super-capacitors can be associated with batteries to enhance the efficiency and longer life cycle.
Keywords –Electric prime mover, DC motor, Battery, Super capacitor, power requirement, small farmers.

I. INTRODUCTION

The total geographical area of the country is 328.73 million ha, of which, 140.13 million ha is net sown area1. The food grain production (279.51 million tonnes) has been surpassed by the horticulture production (305.29 million tonnes from 24.73 million ha area). Indian agriculture employs about 52% of total work force with a GDP contribution of 15% (2016-17)2. It is evident that about 92.30% farm power was coming from animal sources in year 1960-61, whereas, it was 5.81% in year 2016-17. The mechanical and electrical sources of power increased from 7.70 percent in 1960-61 to about 90.12 percent in 2016-17. During the period from 1973-74 to 2016-17, the farm power availability has increased from 0.48 kW/ha to 2.24 kW/ha. The population of electric motors in the country is estimated around 7.5 million. The AC electric motors are primarily used for irrigation and agro-processing purposes as stationary source of power and its power availability per ha is 0.193 kW. The main constraint in Indian agricultural mechanization is due to increasing fragmentation of land holdings, domination of small and marginal farmers, economical status of farmers, environmental conditions, topography, etc. This further increases the challenges of timeliness in farm operations and shortage of farm workers. The output of the farm workers is very low while operating manually operated tools/equipment due to higher workload. Animal power has limited daily working hours and working conditions. The mechanical power source has been adopted in farm operations, due to its higher efficiency, these sources primarily run on fossil fuels. The use of fossil fuel increases the CO2 emissions which has adverse effect on environment. In future, it is, therefore, necessary to establish a bond between the opportunity of sustainable development of agricultural mechanization without neglecting the lack of energy and environmental degradation due to low availability of fossil fuels and its adverse effect on environment.
Considering the above facts, this paper attempts to focus on such innovative solution like electric power to pin the trend of available source of power for farm mechanization. The rest of the paper is organized as follows: Efficiency of available farm power sources are explained in section II, Power requirements in different unit farm operations are presented in section III, Potential of electric prime mover for farm operations is given in section IV, Research work on e-powered device in farm operations is shown in section V, Power requirement assessment for smallholders is calculated in section VI and Concluding remarks are given in section VII.

II. EFFICIENCY OF AVAILABLE FARM POWER SOURCES

The human power output over a working day has been generally accepted as about 70W. Evidence from previous research suggests that 40W would be a more realistic value for developing countries. The level of dynamic workload, which is acceptable, is influenced by the duration and nature of the task. Over a short periods of time, mechanical output of human power can be much higher, approximately 3 kW instantaneously, 1 kW for a minute and 400W for a hour3. Considering the physiological workload of human being in terms of oxygen consumption, the power requirement in different workload varied from 87.2 to 1395W (Table 1).

Table -1 Power requirement by human being under different categories of workload

	Oxygen consumption, l/min	Energy equivalent, J/s	Power, W
Very low workload	0.25-0.3	87.2 – 104.65	87.2 – 104.65
Low workload	0.5-1	174.4- 348.8	174.4- 348.8
Moderate workload	1-1.5	348.8-523.2	348.8-523.2
High workload	1.5-2	523.2-697.7	523.2-697.7
Very high workload	2-2.5	697.7-872	697.7-872.08
Extremely high workload	2.5-4	872-1395.3	872-1395.3

The efficiency of human power source is greater as compared to solar photovoltaic power and thermal plants systems (Table 2)4.

Table- 2 Efficiency of the human power as compared to other systems

	Input Energy Form	Desired Output Form	Max Efficiency
Human	Chemical Potential	Mechanical	25 %
Automobile Engine	Chemical Potential	Mechanical	25 %
Coal/Oil/Gas Fired Stream Turbine Power Plants	Chemical Potential	Electrical	47%
Combined Cycle Gas Power Plants	Chemical Potential	Electrical	58 %
Biomass/Biogas	Kinetic	Electrical	40%
Nuclear	Kinetic	Electrical	36%
Solar-Photovoltaic Power Plant	Sunlight (Electromagnetic)	Electrical	15%
Solar-Thermal Power Plant	Sunlight (Electromagnetic)	Electrical	23%
Hydroelectric and Tidal Power Plants	Gravitational Potential	Electrical	90%+

The average human worker, at rest, produces around 100 watts of power. This equates to around 2000 kcal of food energy. Converting kilocalories into watts using formula Power = Energy/Time.

1 calorie = 4.2 joules, therefore 2000 kilocalories = 8.4 × 106 J

1 day = 86400 s

P = W/t = 8.4 × 106 J /86400 s = 97.22 W

Draft of animals varies according to weight, condition, fatigue and length and severity of work. It is empirically known that the maximum instantaneous force of an animal is approximately equal to body weight in the case of bovines, and may rise up to twice of body weight for equines. Power developed by an average pair of bullocks is about 746W for usual farm work. Usable horse power from a bullock is varied from 0.5 to 0.75hp5.

The thermal efficiency of diesel engine and petrol engine varies from 32 to 38 and 25 to 32 per cent whereas efficiency of DC and BLDC motor varies from 70-75 and 80 to 90 % respectively3.

III. POWER REQUIREMENTS IN DIFFERENT UNIT FARM OPERATIONS

Power required by human beings in carrying out various farm operations are calculated based on their oxygen consumption rate, heart rate and energy expenditure rate are given in Table 3. It is observed that the power requirement varies from 151 W to 713W.

Table- 3 Power consumed by human beings in carrying out various farm activities/ operations8

	Oxygen uptake, l/min or Energy expenditure rate, kJ/min	Work done estimates in terms of Power, W = (VO2 x 20.93x103J/S)
Walking in fields @ 3.86 km/h9	0.5398	188.3

http://dx.doi.org/10.21172/ijiet.134.19

Digging soil with spade	1.586	553.2
Making ridge (130 x 316mm) in pulling mode10	26.7	445
Fertilizer application by manual broadcasting	0.433	151
Fertilizer application by manual broadcaster10	27.9	465
Seeding with manual seeder in wetland	1.638	571.4
Seeding with manual seeder in upland10	26.25	437.5
Weeding with manual weeder	0.932	325.1
Weeding with cono-weeder in wet land11	1.0642	371.2
Spraying of pesticides	0.656	228.8
Harvesting with sickle	0.912	318.1
Rice threshing by manual beating	0.92	320.90
Rice threshing with pedal thresher	1.310	457
Maize dehusking-shelling with dehusker-sheller12	0.939	327.5
Grain cleaning with hanging type grain cleaner	15	250W
Winnowing (standing)	0.808	281.86
Groundnut decortication using decorticator	0.656	228.8
Walking in puddle field	0.750	261.6
Pedalling at 50rpm at 60W power output	0.840	419
Fetching water -Carrying 20-30kg head load13	0.792	276.30
Chaff cutter14	42.18	713.30

A comparative assessment was also made by calculating the power requirement in seeding and ridge making operations with manual operated farm equipment. It was found that the power consumption of human being in ridge making and seeding operations was 7.6 to 9.13 times higher than the power required in pushing or pulling equipment10. While in chaff cutting the power consumption of human beings with chaff cutter was 1.4 times higher than the power required14. It indicates that human beings internal (instantaneous) power is being utilized for operating equipment. It further indicates the need of rest pause in performing the activities as per power consumption requirement.

Draft requirement for manually operated farm equipment (Khurpi, Kasola, Grubber hoe, Wheel hand hoe, Paddy weeder, Hand drill, Serrated sickle, Maize sheller and Groundnut decorticator) varied from 29N to 118N6,7 while draft requirement of animal drawn equipment (desi plough, MB plough, disc harrow, 3-tyne cultivator, bakhar blade, seeding attachment, 3-row seed-cum-fertilizer drill, Local cart, Improved cart and Persian wheel) varied from 294N to 785N with a pair of bullock6.

IV. POTENTIAL OF ELECTRIC PRIME MOVER FOR FARM OPERATIONS

Electric motors are mechanically very simple and its energy conversion efficiency is considered about 90%. Electric Vehicle 'tank-to-wheels' efficiency is about a factor of 3 higher than the internal combustion engine vehicles15.

Some experiments were conducted to use electrical power which is found an appropriate source because of nonexistence of uncomplimentary materials such sulfur, nitrogen, polycyclic aromatics and air pollution16.

A manufacturer in France have developed 72 kg walk behind type 120 cm-wide harvester for harvesting the spinach, lettuce etc. of 114 cm width on raised bed in poly house and source of power for cutter was 24V electric drive17.

Electric utility vehicle is also developed for use in farms, nurseries, greenhouses and vineyards due to ecological point of view18.

Apparent, challenges were highlighted for the agricultural sector in era of a growing population and the impact of climate change. They analyzed their case studies on 13 parameters for adapting agricultural machinery, e.g., raising the use of electric vehicles (EVs), as one way of meeting such challenges and found one important factor for the respondents is the on-farm generation of electricity (mainly PV) and the infrastructure needed to charge EVs. An implication for environmental policy therefore is that support for on-site generation of renewable energy is likely to pro-mote farmer's interest in EVs of all kinds19.Now-a-days, electric vehicles are found for transport in cities, zoos, airport, railway station, park etc.

Powering the device and vehicles with electricity offers some advantages not available in conventional internal combustion engine (where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit) vehicles as electric motors react quickly, responsive and having better torque. Electric powered devices are often more digitally connected than conventional vehicles. Such device can also reduce the CO_2 emissions that contribute to climate change and smog, improving public health and reducing ecological damage. Further minimizes these emissions even more, if renewable energy such as solar is being used to charge the batteries.

The power source of electric prime mover is the battery or solar panel which acts as a "gas tank" and supplies the electric power to motor, necessary to move the electric Prime mover. This gives acceleration to this prime mover. When the electric Prime mover is idle there is no electrical current is being processed, means no consumption of energy. In agriculture sector, speed requirement of prime mover is low for motive and stationary work, particularly for small landholders and high-tech agriculture. Presently DC motors is available with gear reduction drive. Two types of DC motors are commonly available in the market as per need i.e. Brushed DC motor and Brushless DC motor. Brushless motors are having advantage of long life span, little or no maintenance and high efficiency than brushed DC motor. The lead-acid battery is being used to run DC motor and it increases the running cost of prime mover due to its limited life and battery charging time. These DC motors have potential to be adopted for developing electric prime mover for farm operations to reduce drudgery of farm workers with increased productivity and less impact on environment.

Super-capacitors associated with batteries have been presented as a promising solution20. The super-capacitor characteristics, such as long time in cycles of operation21, make them good options for applications that require a large amount of energy storage and supply in repeated quantities. Moreover, the super-capacitors not only are able to be charged and discharged countless times, but they can also be stored with ten times more energy than the existing capacitors. Besides, they have the merit of a quick charging and discharging of energy and a longer life cycle22.

V. RESEARCH WORK ON E-POWERED DEVICE IN FARM OPERATIONS

A battery-assisted four wheel weeder has been developed for weeding in wide row (more than 30 cm) crops19. The developed machine consisted of brushed DC motor, DMSC, battery, power transmission system, drive-wheels, front wheels, frame and swinging handle (Fig 1). The brushed DC motor (250W) was powered by two 12V-14Ah batteries. Weeding operation in field performed satisfactorily with sweep type tool up to 147N draft. The operator has to only guide the weeder up to 147N draft while they need to apply their muscle power beyond 147 N to prevent slippage. The average field capacity of this machine was found 0.0554 ha/h at speed of 2.52 km/h with 97.5% weeding efficiency.

Figure 1. Battery-assisted four wheel weeder

An electric powered two-row multi-purpose seeder has also been developed for sowing spinach, coriander and wheat seeds23. The unit consisted of 24V, 350W DC geared motor, two 12V-14Ah batteries, power transmission unit, independent seeding units with vertical cell fed metering mechanism, swinging handle and frame (Fig 2). From field studies, output with electric powered seeder was 1130 m2/h at speed of about 2.9 km/h with field efficiency of 90.3% for spinach, coriander and wheat seeds. The average draft requirement of machine was 106.1N. The developed equipment provided 2.5 times more output than manual operated seed drill with reduced drudgery by 2.6 times in terms of muscular force requirement.

Figure 2. Electric powered multi-purpose seeder

A walk-behind e-power assisted single row offset rotary cutter was also developed for cutting spinach and coriander24 (Fig 3). The cut crop is laid in windrow which is lifted manually. The developed cutter consisted of 250W DC motor, two 12V- 12Ah batteries, power transmission unit, rotary blade with provision to lay crop in windrow, frame and handle. The cutting width was about 100mm with the rotary blade. The output with the cutter for cutting Spinach was 193.3 m2/h at speed of 0.9 km/h while it was 172 m2/h at speed of 0.8 km/h. The overall output with cutter including making bundle of spinach and coriander was 82.8 m2/h and 80.9 m2/h, respectively. The efficiency enhancement with cutter over manual cutting was of 2.56 times to manual cutting of spinach with sickle.

Figure 3. e-Power assisted single row offset rotary cutter

The above studies clearly indicated that 350W brushed DC motor with 12V 14Ah batteries is sufficient for two row seeding, weeding and cutting row vegetable crops (spinach and coriander leaves). The power can also be successfully utilized for spraying, 30 cm size of ridge or furrow making in pulverized field, stationary uses like paddy threshing with loop type thresher, winnower etc. A 200W solar panels can also be used for charging the batteries for mobile operations and continuous use of solar panels for stationary operations with batteries.

VI. POWER REQUIREMENT ASSESSMENT FOR SMALLHOLDERS

The average farm size in the country is less than 1.08 ha. Small and marginal farmers having less than 2 ha contribute to 86% of total operational land holdings and cover 47% of total operated area25. Numbers of marginal farmers are expected to be more due to reduction in family size. On the basis of gross cropped area, optimum power requirement was found 597 to 746 W/ha26 using Hunt's formula27while it was 261-283 W/ha with Chancellor's model28. Considering system efficiency, the BLDC motor of 1kW was assessed as power requirement (746W) for 1ha cropped area. System efficiency includes efficiency of motor, traction and power transmission. Functional power for agricultural operations with 1 kW BLDC motor are worked out by considering power losses in motor (15%), traction (20%) and 10% in power transmission as per standard formula. Therefore, available power is 550W for meeting functional requirement of equipment in field and accessible pull force will be 657N which is sufficient for secondary tillage (cultivator), ridge making, seeding, weeding, spraying and stationary operations like paddy threshing, winnowing, grading etc. by developing matching equipment with the prime mover.

VII. CONCLUSION

The present study clearly indicates that the utilization of electric power in different farm operations has gained immense attention from the last few years. It was noticed from the literature, the sowing, weeding and cutting operations with 250 to 350W brushed DC motor has reduced drudgery of farm workers with increased productivity in these operations. Based on this study, 1kW BLDC motor size will be optimum for mobile and stationary farm operations (the equipment operated by human and animal source of power) for small farm holders (up to 1 ha). Solar photovoltaic cell can be successfully utilized for battery charging and can also be directly utilized for stationary operations. The electric prime mover certainly will be a more sustainable technology to reduce the drudgery of farm workers with increased productivity and less impact on environment. The main barrier of technology is the cost and life of batteries which can be overcome by increasing its utilization for other field operations. Future research should be directed towards use of super capacitor battery which has quick charging time, more power density, light weight and environmental friendly as compared to existing batteries being used in agricultural vehicles.

VIII. REFERENCE

[1] GOI, "Agricultural Research Data Book (ARDB)",http://iasri.res.in/agridata/17data/HOME_17, 2017.
[2] C. R. Mehta, N. S. Chandel, P. C. Jena, and A. Jha, "Indian agriculture counting on farm mechanization", Agricultural Mechanization in Asia, Africa and Latin America, vol. 50 no. 1, pp84-89, 2019.
[3] FAO, "Testing and Evaluation of Agricultural Machinery and Equipment- Principles and practices", FAO Agricultural Service Bulletin 110, FAO of United Nations, Rome, pp74-75, 1994.
[4] Chapter 85. "Efficiency of the Human Body", https://openoregon.pressbooks.pub/bodyphysics/chapter/human-metabolism/
[5] B. B. Singh, "Principles of Agricultural Engineering", Singhal Book Depo, Barot, Meetut, pp 12, 1988.
[6] D. N. Sharma, and S. Mukesh, "Farm Machinery Design: Principles and Problems", Jain Brothers, New Delhi, pp374, 2013.
[7] S. P. Singh, U. Ekka, Mukesh. K. Singh, and M. K. Singh, "Mathematical model for design of farm equipment suitable to relevant workers", Agricultural Engineering International: CIGR Journal, vol. 20 no. 3, pp141–150, 2018.
[8] ICAR, "Handbook of Agricultural Engineering", DKMA, ICAR, New Delhi, pp771, 2013.
[9] Muni Sekhar K, Bhide Arpana, Hemalatha, Shiva Krishna G, "Comparison of energy expenditure during walking and running on track before and after training in young healthy adult women", International Journal of Physiotherapy and Research, vol. 1 no. 4, pp143-47, 2013.
[10] S. P. Singh, "Ergonomical evaluation of some selected manually operated farm equipment with men workers", Journal of The Institution of Engineers (India), vol/ 90, June, pp18-22, 2009.
[11] S. P. Singh, "Ergonomic evaluation of cono-weeder with farm women", Agricultural Engineering Today, vol. 34 no. 3, pp31-36, 2010.
[12] S. P. Singh, Surendra Singh and Pratap Singh, "Ergonomics in developing hand operated maize dehusker-sheller for farm women", Applied Ergonomics, vol.43, pp792-798, 2012.
[13] Rohit Sharma and Ranjit Singh, 2012. Determination of Safe Carrying Load Limit for Women Carrying Water. Journal of Ergonomics, vol. 2, no.2, 1-7, 2012.
[14] Adarsh Kumar, J. K. Singh, and Charanjit Singh, "Ergonomic Assessment of a Manual Fodder Cutter", Journal of Agricultural Engineering, vol.47, no. 4, pp1-9, 2010.
[15] https://en.wikipedia.org/wiki/Electric_vehicle#cite_note-ec.europa.eu-106
[16] S. W. Lee, T. Herage, and B. Young, :Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel" CANMET Energy Technology Centre, vol. 83, pp1607–1613, 2004.
[17] www.terrateck.com/en/vegetable-harvester/154-babyleaf-harvester.html
[18] https://www.alke.com/electric-vehicles-catalogs
[19] Mukesh K. Singh, S. P. Singh, M. K. Singh, and U. Ekka. "Battery-assisted four-wheel weeder for reducing drudgery of farmers",Indian Journal of Agricultural Sciences (accepted), 2019.
[20] Redpath, D. A. G., McIlveen-Wright, D., Kattakayam, T., Hewitt, N. J., Karlowski, J. and Bardi, U. "Battery powered electric vehicles charged via solar photovoltaic arrays developed for light agricultural duties in remote hilly areas in the Southern Mediterranean region". Journal of Cleaner Production 19 : 2034-2048, 2011.
[21] TAN, C.W., TIE and S.F. "A review of energy source and energy management system in electric vehicles". Renewable and Sustainable Energy Reviews, v.20, p.82-102, 2013.
[22] REDDY, and E.G. "Power management of supercapacitors using multi boost and full bridge converters used in electric / hybrid electric vehicle". International Journal of Engineering Science and Technology, v.3, p.4774-4784, 2011.
[23] S. P. Singh,Mukesh K. Singh, U. Ekka and M. K. Singh, "e-Powered multi-purpose two-row seeder for smallholders", Indian Journal of Agricultural Sciences (accepted), 2019.
[24] IARI, "E-Power assisted Spinach-cum-coriander offset rotary cutter", IARI Annual Report 2018-19, Indian Agricultural Research Institute, New Delhi, pp82-83, 2019.
[25] GOI, "Agriculture Census 2015-16 (Phase I) Provisional Results", Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India (GOI), 2018.
[26] A. Prakash, "Determination of Optimum Sized Tractor & Optimum Field capacity for some selected farms", Un-published M. Tech (FMP) Thesis, JNKVV, Jabalpur, 2009.
[27] D.Hunt, "Farm power and machinery management", 8th Ed. Iowa State University Press, Ames, 1983.
[28] W.J. Chancellor, "Selection of optimum sized tractor", Transactions of A.S.A.E. pp. 411- 418, 1969.