Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 8 Issue 4, April - 2021

Potential Energy Storage System for Autonomous AC Microgrid

Daming Zhang
School of Electrical Engineering and Telecommunication
University of New South Wales
Australia, 2052
Email: daming.zhang@unsw.edu.au

***Abstract*— This paper presents more structures of linear machines used for potential energy storage system and its application in AC autonomous microgrid. Comparison between double-O and double-U structures has been briefly conducted. It is found that double-O has less space leakage flux. Nevertheless with sufficient separation between two arms with distributed air gaps in double-U, the space leakage flux could be contained within limit to avoid malfunctioning its operation. By further adopting non- or less conductive composites reinforced by stainless steels to be supports of mover coils, induced voltages on them due to such space leakage flux are reduced. Then the amount of magnetic material usages for two topologies is close to each other. Furthermore this paper presents one drive circuit for the mover windings.**

***Keywords*— Composites; leakage flux; microgrid; potential energy storage.**

I. INTRODUCTION

Large autonomous microgrid technology can be adopted to maximize harnessing of renewable energy generation, thereby reducing the reliance on fossil fuel[1-2]. To cope with the drastic difference of inertias between conventional synchronous generator based generation and inverter based renewable generation, different regions are formed. In some of them there are only conventional synchronous generators while in other regions there are only inverter based renewable generations. To cope with intermittency of renewable generation, energy storage is indispensable. One can adopt potential energy storage together with flywheel and/or super-capacitors to solve the problem.

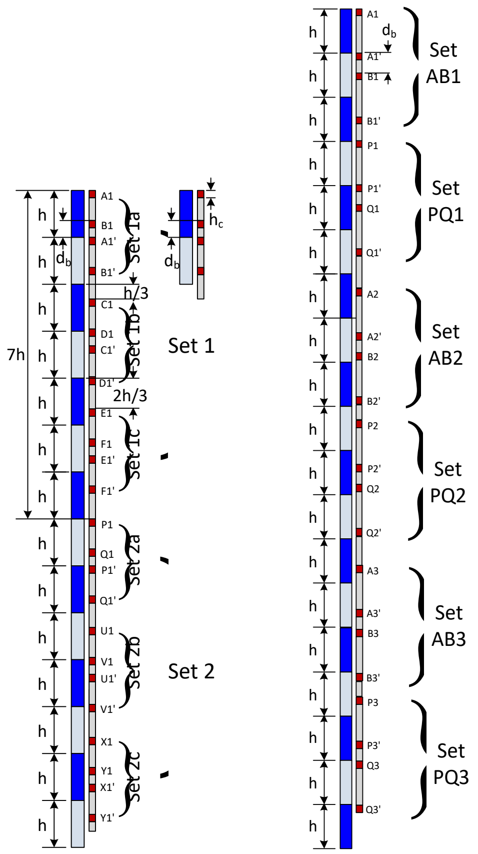
In previous publications by the author[3-7], many aspects of the linear machine systems for potential energy storage have been studied. Nevertheless there are still spaces for improvement, some of which are addressed in this paper.

In the following sections, Section II describes modified potential energy storage system. Section III concludes the paper.

II. IMPROVED POTENTIAL ENERGY STORAGE SYSTEM

For the designs that there are n-sides of n-mover coils spanning one stator vertical layer, when one coil experiences the transition between stator magnetic layer and non-magnetic layer, there are induced voltages in other neighboring coils[3-6]. To solve this problem, two feasible mover coil arrangements are proposed as shown in Fig. 1.

As stated in [6], each coil such as A1A1' in Fig. 1 is formed by several turns in series. In the mover winding design shown in both Fig. 1a and Fig. 1b, d_b should be longer than the mover conductor vertical length h_c in order to accommodate insulation, and casings, and have sufficient clearance distance. Such a mover configuration in Fig. 1a still has the issue of induced voltage during transition. The one shown in Fig, 1b can significantly reduce the induced voltage, though compromise is that the vertical length of the mover is longer.



(a) (b)

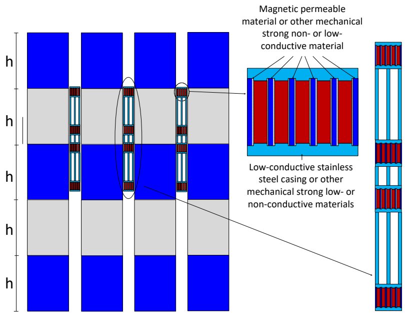
Fig. 1. Mover winding arrangements with reference to interleaved stator layers

To make the transition of the mover conductors between magnetic and non-magnetic stator layers easier, the vertical height h_c of the thin mover conductors as indicated in Fig.1a should be as small as possible. But such reduction leads to smaller electromagnetic force produced, thereby reducing heavy masses lifting capability. Optimization can be done to reach optimal h_c.

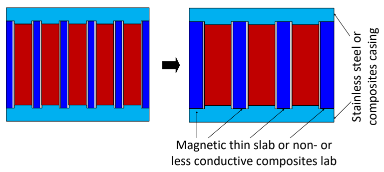
Instead of using large vertical span h for each stator layer as shown in Fig. 1, one may reduce it to smaller one. Then when pulse voltage is applied for the current in one mover coil to reverse its direction during its transition between magnetic and non-magnetic layers, there is negligible induced voltage in another coil in Fig. 1a.

In Fig. 1, there could be four or more sub-sets instead of three sub-sets in each set in order to carry heavier containers with masses.

The number of turns in each mover coil or winding accommodated in each of the distributed air gaps as shown in Fig. 2 can be reduced to several turns. The width of each thin mover conductor is increased accordingly. For such an arrangement, parallel driving circuits could be used in order to have higher current. The thickness ratio of the magnetic permeable thin slab for enhancing mechanical strength to that of the mover thin conductors should be kept as small as possible so long mechanic strength requirement is satisfied. Alternatively other non- or less conductive and non- or less magnetically permeable and mechanic strong materials, such as some composites can be used to replace the magnetic permeable thin slabs.



(a)

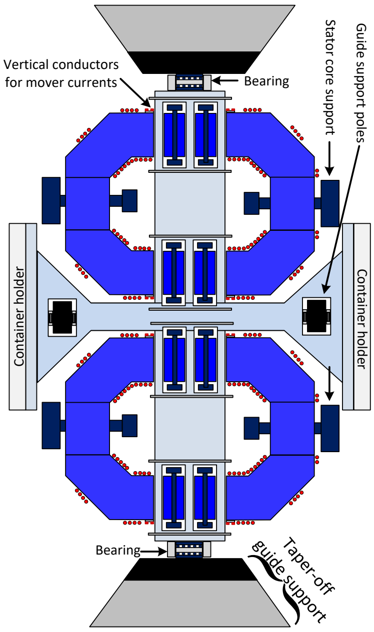


(b)

Fig. 2. Mover windings sandwiched between magnetic plates and placed in a casing

By having less turns in each coil, the armature reaction by the mover currents are contained to a tolerable level. Furthermore instead of using 500A flowing through the mover coils[3-5], smaller currents can be adopted. To lift equal containers with heavy masses, longer mover along vertical direction needs be designed.

When the stator coils are wound layer by layer on each stator magnetic layer and connected in series [6], necessary clearance distance between neighboring turns wound on each stator magnetic layer is necessary as there are high voltages induced in them during transition of mover coils between stator magnetic and non-magnetic layers, though they cancel each other seen from two terminals of the overall stator winding. For such a situation, filtering capacitors in parallel with overall stator winding needs be used to reduce the impact of the induced narrow pulse voltage on the converter circuit for driving stator windings. Nevertheless straight up-down stator winding style as shown in [3-6] can avoid the issues of induced high voltage in stator windings, though the higher permeability of the stator cores is required. When the straight up-down stator winding is used, multi-layer configuration as shown in [6] needs be adopted, each layer being around 100m vertically.



.

Fig. 3. Top view of a possible configurations without showing joining parts at the top

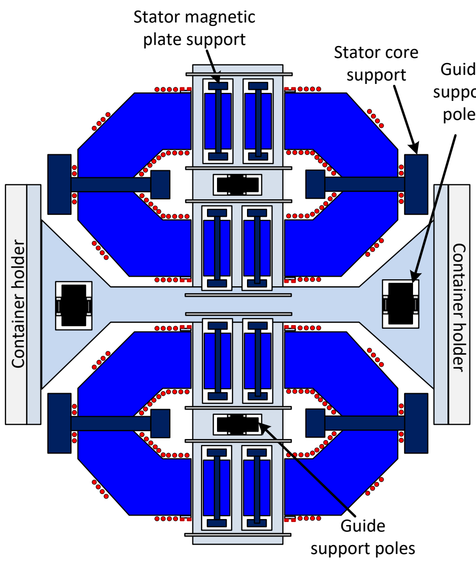


Fig. 4. Top view of the configuration with different mover support poles

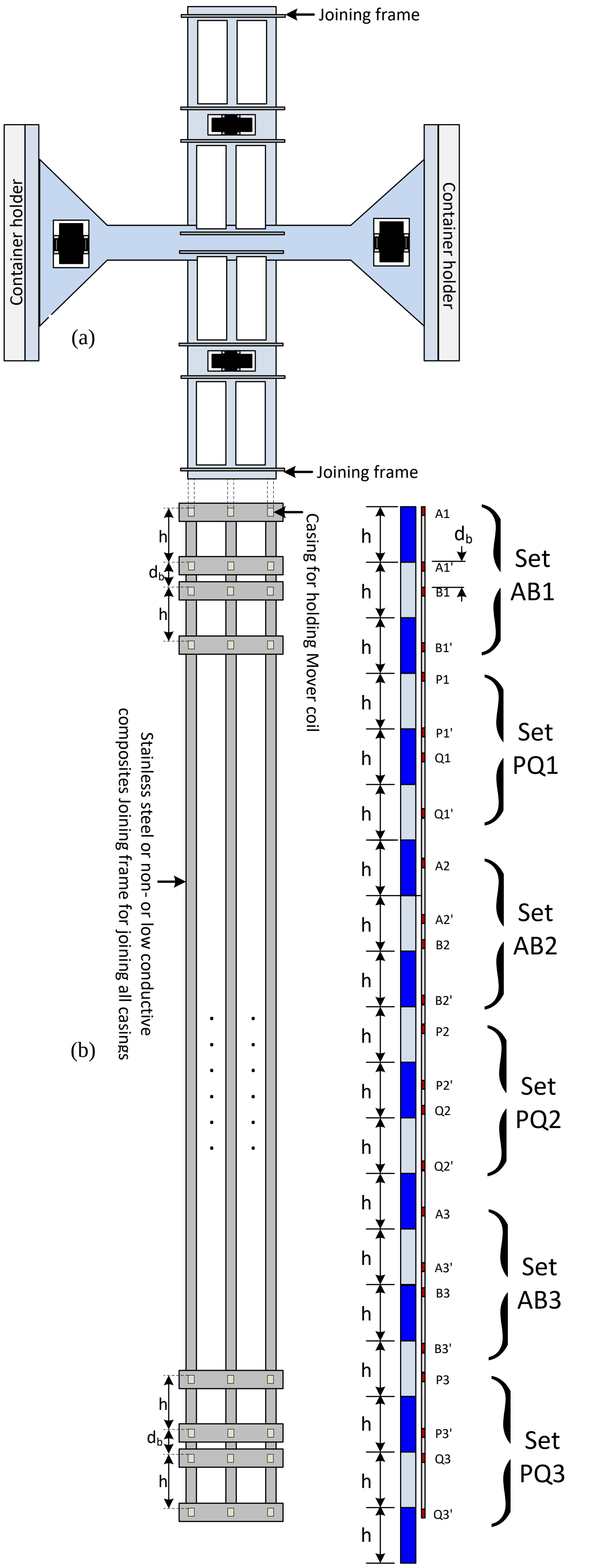


Fig. 5. (a) Top view of mover from that in Fig. 4; (b) Side view of the mover side support

If the different sets of stator windings are identical, they can be connected either in parallel or in series. To avoid problems, it is advised that symmetrical stator configurations should be adopted.

As stated in [6], the stainless steel or stainless steel reinforced concretes support poles for stator cores, the mover winding guide poles and magnetic plate supports are joined together at the top to increase system mechanic strength. The whole support is installed on strong base at the bottom. Furthermore, tapering-off support made of steel reinforced concretes should be adopted to reinforce the whole support structure.

Those mechanic supports for mover conductors, including casings, inter-connections between casings, joining supports with main mover frame are made of low-conductive stainless steels. Composites with low- or non-conductive and low- or non-magnetically permeable, and mechanic strong properties in bolts form should be used to link different parts of the stainless steel structures to avoid the influence by the induced eddy currents during movement of the mover. Certainly all the casings and their supports of mover windings can be made of such composites etc.

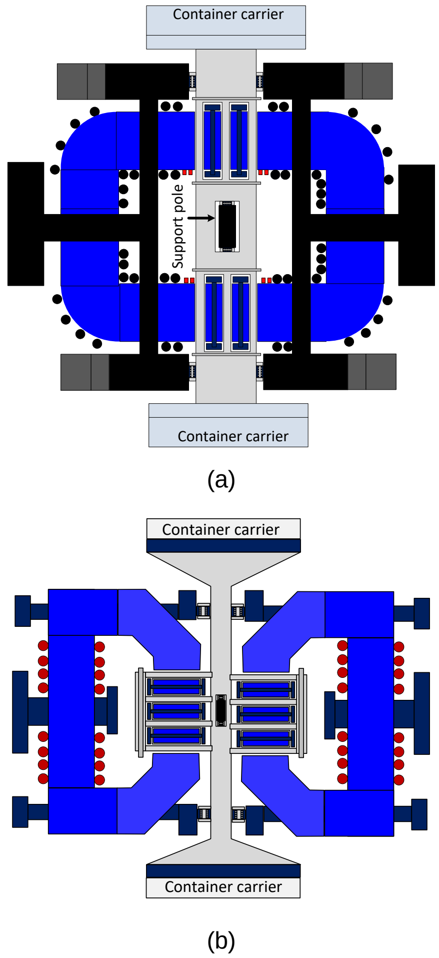


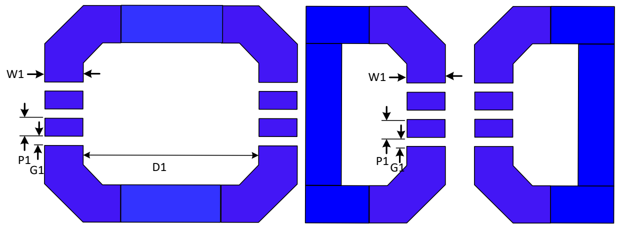
Fig. 6. Top view of double-U and double-O structures without showing joining parts at the top

Figs. 3 through 5 show the improved double double-U topology which is for larger system design. Nevertheless such a system could be very difficult to implement as precision requirement is high and could be around a very small fraction of one millimeter.

Fig. 5b shows the side view of the joining frame of all casings. Such frames exist on both sides of the mover coils. These frames are further joined with other mechanic supports for the mover windings.

Fig. 6a shows a single double-U structure while Fig. 6b illustrates a double-O structure. Compared with double-U, double-O has much less space leakage magnetic flux.

To avoid such large flux leakage, the D1 in Fig. 7a should be as large as possible compared with the total air gap distances in the closed loop of the stator magnetic path. But to save the magnetic materials, it should not be too much. If D1 is five to six times of the total air gap distance, then most magnetic fluxes pass through the distributed air gaps and a small amount returns directly in space. Optimization can be conducted to reach a suitable ratio of D1 to total air gap length. When non- or less conductive composites are adopted to reinforce mover coils and act as insulations, such space leakage magnetic flux poses less influence.



(a) (b)

Fig. 7. Comparison of a) double-U and b) double-O

Part of the dimensions for the system in Fig. 1 and Fig. 7a is shown in Table I as an example design.

In the system design, besides force balance, one also needs to check the torque balance for proper transient balance.

Fig. 8 shows one drive circuit for mover coils. The core forming unit contains 50Hz AC/DC rectifier/inverter, DC link capacitor, DC/AC medium-frequency inverter/rectifier, medium-frequency transformer, medium-frequency AC/DC rectifier/inverter, DC link capacitor, single-phase DC/AC full bridge converter. One possible configuration of single-phase DC/AC full bridge converter is shown in Fig. 9. It is a DC/AC converter because it suits both generating and motoring operation modes. It works as DC/DC converter to regulate mover coil current to certain value when the mover coil is in non-transitional movement. After transition, the current reverses direction and the converter regulates its value to new targeted value.

During transition when the mover coils transits between stator magnetic and non-magnetic layers, bi-directional switch 714 is turned on to flywheel the mover coil current. After its being on with tens of microsecond delay, switches 720 is turned off. Such procedure could cause a current spike experienced by the circuit. Due to parasitic and contact impedances in the circuit, such spike is kept not too high. Alternatively, one can use a small resistor in series with capacitor 706. When transition is to happen, one can turn off switches in 705 first, then switches in 714 are turned on to flywheel the mover coil currents. After a short delay, switches 720 are turned off. After that, switches in 707 and other cascade units change positions to be prepared to provide negative voltage to quickly force the current in the mover coil to zero and then reverse direction.

The mover drive circuits in Figs. 8 and 9 are bi-directional allowing operation in both motoring and generating modes.

These circuits can be modified to suit driving stator winding purpose.

Table I Dimension of an Example Design for Fig. 7a

	Values
Each air gap G1 in Fig. 7a	6.0cm
Plate width P1 in Fig. 7a	Around 3-4 times as long as each distributed air gap
Width of magnetic core W1 in Fig. 7a	80cm
Stator vertical layer distance h	50cm
Mover thin conductor vertical length h_c in Fig. 1	6.0cm
Mover thin conductor thickness	0.36cm each
Mover thin magnetic permeable slab support thickness	Needs hardware test, estimated to be around 0.10cm
Separation distance d_b in Fig. 1	7.5cm
Number of mover conductor turns in one coil accommodated in each air gap in Fig. 2b	12
Total number of air gaps	6, three on each of two sides
Distance D1 in Fig. 7a	Around five to six times of the total distributed air gap length in one closed magnetic path for the stator
Proposed mover speed for Fig. 1a	Several m/s
Proposed mover speed for Fig. 1b	Faster than that in Fig. 1a

Table II Dimension of an Example Design for Fig. 7b

	Values
Each air gap G1 in Fig. 7b	6.0cm
Plate width P1 in Fig. 7b	Around 3-4 times as long as each distributed air gap
Width of magnetic core W1 in Fig. 7b	80cm
Stator vertical layer distance h	50cm
Mover thin conductor vertical length h_c in Fig. 1	6.0cm
Mover thin conductor thickness	0.36cm each
Mover thin magnetic permeable slab support thickness	Needs hardware test, estimated to be around 0.10cm
Separation distance d_b in Fig. 1	7.5cm
Number of mover conductor turns in one coil accommodated in each air gap in Fig. 2b	12
Total number of air gaps	6, three on each of two Os

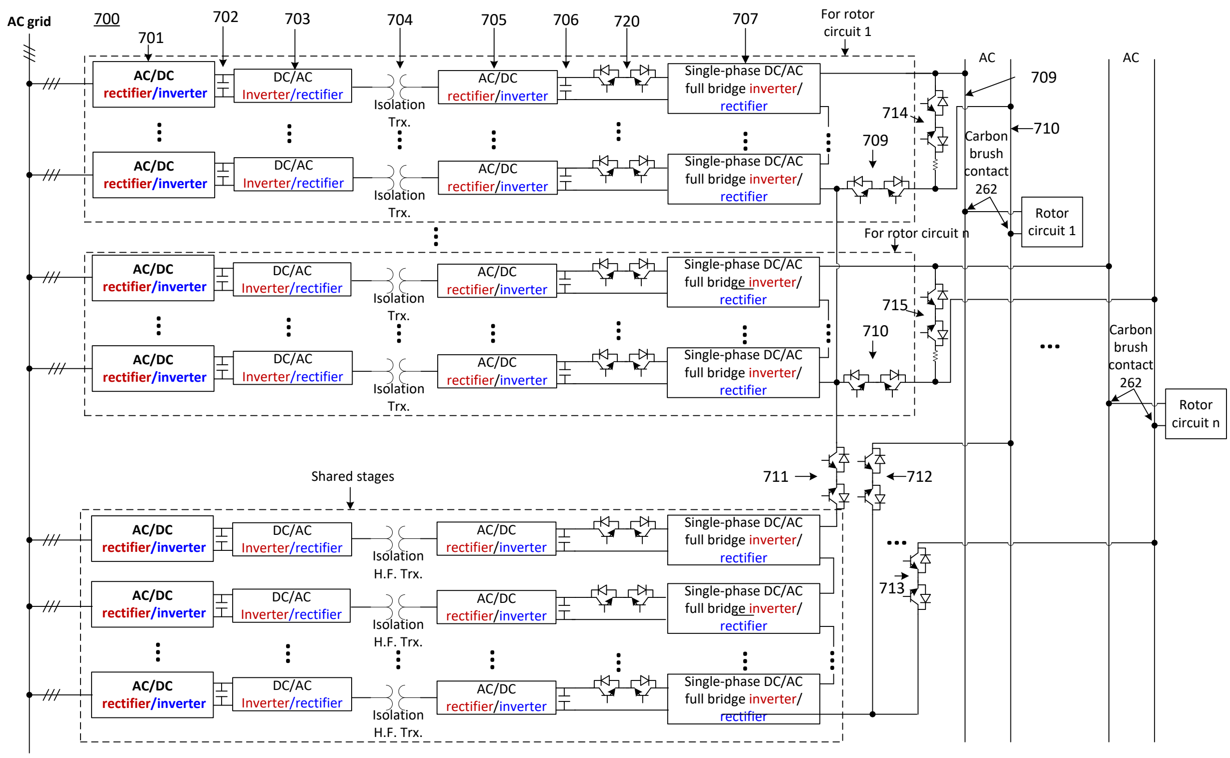


Fig. 8. Drive circuit for mover windings

Table I shows an example for double-U structure while Table II shows an example for double-O structure.

Although scale-down design can be adopted, its profit return years will be extended.

As stated in earlier publications, such a system can be built along the slopes of mountain/mount or it can be built on dry land preferable on small mounds by excavating downward to form low platforms for parking containers with heavy masses. Multilayer is preferred[6].

A low-efficiency, much cheaper potential energy storage system is given in [7]. One may combine the low-cost design in [7] with high-efficiency design proposed in this paper to cope with the challenge of solar/wind generation intermittency and high efficiency requirement. When there is a gust of wind, multiple machine systems in [7] are activated to store the energy. Wind or solar energy is converted into electricity then further converted into potential energy stored in heavy masses in containers parked at high parking lot or platform. It could be better to use a separate autonomous microgrid to achieve the potential energy storage purpose.

When there is a shortage of wind and solar energy, containers with heavy masses from the high parking lot are moved by the machine system proposed in this paper to low parking lot, and the potential energy stored in heavy masses is converted into electricity, part of which is fed into microgrid to meet load demand, while the other of which is stored temporarily in flywheels or battery banks, and/or super-capacitors, then it is released gradually to meet load demands.

The autonomous AC microgrid in [8] can be integrated with the proposed energy storage system. The controller parameters used in hardware test in [8] are different from those in simulation, in which many sets of parameters with large variation work. Nevertheless out of K_p, K_i and K, K used in hardware test can be quite small. In some cases it could be as small as around 10.

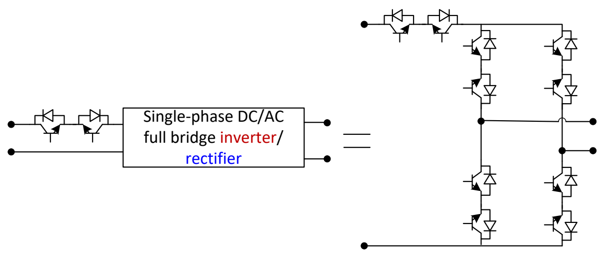


Fig. 9. Bi-directional DC/AC converter

III. Conclusion

This paper presents a comparison between double-U and double-O stator topologies for potential energy storage system. It is found that double-U structure could be made equivalent to double-O structure by having sufficient separation between two sides with distributed air gaps. Nevertheless double-O configuration still has the advantage of smaller leakage flux in space.

This paper further presents a driver circuit for the mover winding structure which has the feature of bi-directional power flow.

REFERENCES

[1] Daniel E. Olivares, and Nikos D. Hatziargyriou, "Trends in Microgrid Control", IEEE TRANSACTIONS ON SMART GRID, Vol. 5, No. 4, pp.1905-1919, JULY 2014.

[2] Daming Zhang, "Operation of Microgrid at Constant Frequency with a Standby Backup Grid-forming Generator", PowerCon 2016, Wollongong, Australia.

[3] Daming Zhang, "Review on Heavy Mass Energy Storage and a New Such a System Using Interleaved Magnetic Structure", AUPEC 2018, Auckland, New Zealand, pp. 1-8.

[4] Daming Zhang, "A Heavy Mass Energy Storage System Using an AC-DC Linear Machine with Multiple Rotors and Enhanced Lifting Force", Journal of Multidisciplinary Engineering Science and Technology (JMEST) on-line link: http://www.jmest.org/, ISSN: 2458-9403, Vol. 6, Issue 1, January – 2019.

[5] Daming Zhang, "Issues on Series-Parallel Circuits and their Drives in the Linear Machine for Heavy Mass Energy Storage System", ACPEE, Hangzhou, China, pp. 1-11, March 2019.

[6] Daming Zhang, "Improved Heavy Masses Potential Energy Storage Systems", Journal of Multidisciplinary Engineering Science and Technology, on-line link: http://www.jmest.org/vol-8-issue-2-february-2021/.

[7] Daming Zhang, "Heavy Mass Energy Storage with Magnetic Levitated Wheels, Bearings and Locomotive", Journal of Multidisciplinary Engineering Science and Technology (JMEST) on-line link: http://www.jmest.org/, July 2019.

[8] Daming Zhang, Xiuhui Tang, and John Fletcher, "Voltage Profile Improvement in Autonomous AC Microgrid Operated at Constant Frequency and Equivalent Parallel Operation of Inverters", IEEE Region Ten Conference (TenCon), on-line conference, Japan, 2020.