Application of solar photovoltaic system to power air blower and mixing mechanism in a tilting furnace

Philip O. Babalola*, Christian A. Bolu, Anthony O. Inegbenebor, Sunday O. Oyedepo and Oluwaseun Kilanko

Mechanical Engineering Department,
College of Engineering,
Covenant University, Nigeria
Email: phillip.babalola@covenantuniversity.edu.ng
Email: christian.bolu@covenantuniversity.edu.ng
Email: anthony.inegbenebor@covenantuniversity.edu.ng
Email: sunday.oyedepo@covenantuniversity.edu.ng
Email: oluwaseun.kilanko@covenantuniversity.edu.ng
*Corresponding author

Gideon A. Adeyemi

Civil Engineering Department,
College of Engineering,
Covenant University, Nigeria
Email: gideon.adewale@cu.edu.ng

Abstract: Gas and oil-fired furnaces require air blower and stirring mechanism to produce homogeneous metal matrix, alloyed metals and metallic composites. Both the blower and the stirrer require electric power that is not reliable in some urban areas and non-available in some rural communities in sub-Saharan countries. In this paper, a 20 kg oil-fired tilting furnace for melting iron, gold, aluminium, lead, magnesium, copper, tin et cetera and also used to produce metal matrix composites through liquid metallurgy routes, is designed for off-grid locations. Photovoltaic system specification of 250 W solar panel, 20A charge controller, 300 AH deep cycle battery and 1,400 W inverter were used to provide electric power to the air blower and mixing motor of the tilting furnace. With this arrangement, this versatile tilting furnace could be used in cottage industry without electric mains by small and medium-scale enterprises (SMEs), thus reducing unemployment among the populace and reduction of emission products into the atmosphere.

Keywords: renewable energy; solar photovoltaic; tilting furnace; aluminium; small and medium-scale enterprises; SMEs; MMC.

Reference to this paper should be made as follows: Babalola, P.O., Bolu, C.A., Inegbenebor, A.O., Oyedepo, S.O., Kilanko, O. and Adeyemi, G.A. (xxxx) 'Application of solar photovoltaic system to power air blower and mixing mechanism in a tilting furnace', *World Review of Science, Technology and Sustainable Development*, Vol. X, No. Y, pp.xxx–xxx.

Biographical notes: Philip O. Babalola is a Lecturer and researcher at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on composite materials, renewable energy applications, and thermo-fluid with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and corporate member of the Nigerian Society of Engineers.

Christian A. Bolu is a Professor at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on engineering materials, industrial engineering, and mechatronics with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and a Fellow of the Nigerian Society of Engineers.

Anthony O. Inegbenebor is a Professor at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on engineering materials, and metallurgy with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and a Fellow of the Nigerian Society of Engineers.

Sunday O. Oyedepo is a Professor and Head at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on turbine power plants, renewable energy, and refrigeration systems with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and a Fellow of the Nigerian Society of Engineers.

Oluwaseun Kilanko is a Lecturer and researcher at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on machine design, manufacturing engineering, modelling and simulation with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and corporate member of the Nigerian Society of Engineers.

Gideon A. Adeyemi is a Lecturer and researcher at the Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on remote sensing and geographical information systems.

This paper is a revised and expanded version of a paper entitled 'Application of solar photovoltaic system to power air blower and mixing mechanism in a tilting furnace' presented at International Conference on Engineering for a Sustainable World (ICESW 2017), Covenant University, Ota, Nigeria, 3–7 July 2017.

1 Introduction

Availability and reliability of public electrical power in Sub-Saharan countries like Nigeria is an unending nightmare. Unfortunately, many locations in developing nations are confronted with at least one of the followings electricity power issues: non-availability, available but epileptic in nature, destructive low voltage, destructive high voltage, high tariff, constant upward review of tariff, unmetered energy consumption bills, and deliberate extortion from utility company. The list seems to be endless. These problems faced by the consumers could be traced to power generations, transmitting same or distribution to the end users by the utility companies. This is far from being acceptable to small and medium-scale enterprises (SMEs) in the present global highly competitive environments. Local foundry establishments depend on generators with varied capacities depending on the size of the setup. This is an increase in production cost with the added disadvantage of more emission into the atmosphere.

Renewable energy sources (RES) can be used to bridge the gaps between energy demand and generation. This is achieved by converting RES in the form of biomass, wind, solar, micro-hydro, and geothermal energies into electrical energy and delivered such to demand centres or utility grids. Another advantage from RES is the provision of clean, safe, clean and sustainable energy. However, solar energy is deemed as the most reliable and viable options among all RES in tropical countries (Madeti and Singh, 2017), this is very true taking Nigeria as an example. Wind energy is only viable along coastal communities, northern border and mountainous communities. Hydro power on its part requires water from river/stream with steep valley for water storage. These are not readily available everywhere. Biomass, though renewable takes longer time to be replenished and will also readily produce emission no matter the efficiency of the burner (Kaur et al., 2014). However, solar energy could be harvested wherever there is green plant; topography and location notwithstanding, and without the production of harmful emissions like carbon dioxide. Hence, there are myriad applications of solar electricity (photovoltaic) to power residential apartments (Vieira et al., 2017; Sun et al., 2016; Okoye and Solval, 2017; Tam et al., 2016; Cucchiella et al., 2016; Zhan et al., 2016; Abanda et al., 2016; Huide et. al., 2017), electric vehicles (Ezzat and Dincer, 2016; Castro et al., 2017; Bhatti et al., 2016), equipment (Matthews et al., 2016; Romantchik et al., 2017; Popoola et al., 2017) and in agriculture (Xue, 2017). Agricultural application includes greenhouse accessories, water pumping, wastewater treatment, breeding and rural power station.

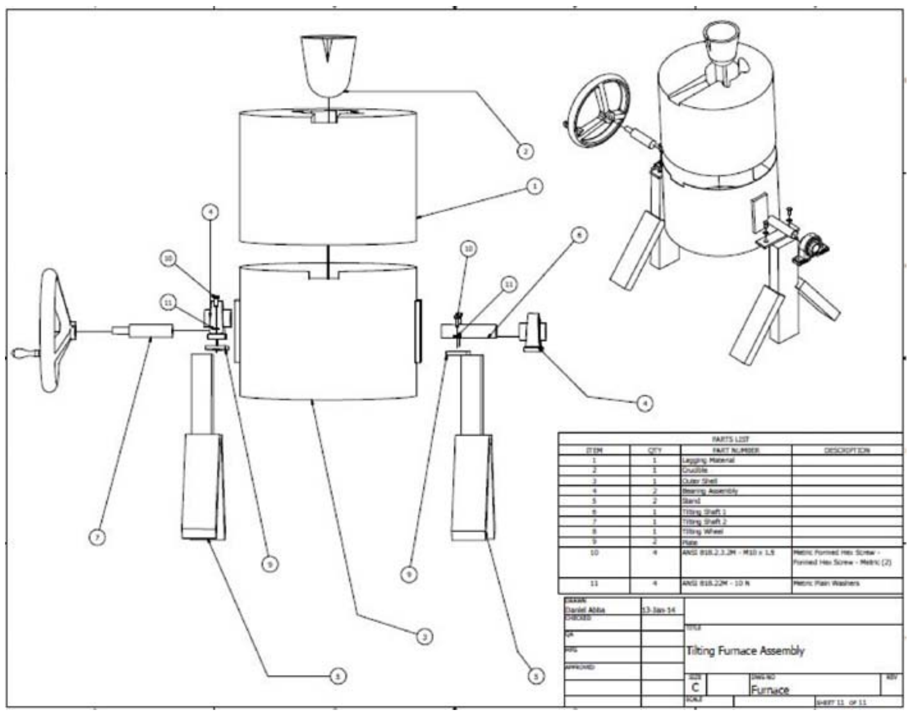
According to Oyedepo (2012), Nigeria has tremendous solar energy potentials because of her situation so close to the equator having high sunshine rate. Total solar radiation mean annual average varies from 3.5 kW m^{-2} day^{-1} in the coastal latitude to 7 kW m^{-2} day^{-1} along the Savanna areas in the North. On the average, the country receives solar radiation at the level of 19.8 MJ m−2 day−1. He estimated sunshine hours to be 6 h per day (Oyedepo, 2012). This huge potential is largely underutilised.

In this work, solar energy was converted to electrical energy using solar panel. The electrical energy was then used to power both electric air blower and stirrer required for the operation of 20kg tilting furnace. With this arrangement, the furnace is operational in remote cottage industry (SMEs) in tropical region without public electricity supply or use of reciprocating internal combustion engine (RICE) electrical generator.

2 Overview of tilting furnace

A furnace is a device in which heat is produced by burning fuel to undertake an industrial process such as smelting metal. The burning of fuel is a combustion process requiring mass flow of air. The air is usually provided using electric blowers depending on the capacity and application of the furnace. Mixing the melt is necessary for homogenisation of the melt and a must during alloying of base metals and reinforcement of matrix metals in composite manufacturing. Most manufacturing processes employed electrical energy to power the blower and mixing mechanism. The use of fossil powered electrical generators invariably leads to increase in carbon imprint of the manufacturing process and it is not eco-friendly. Hence, electric power generated using photovoltaic source is used to power a tilting furnace (Babalola et al., 2012) in this work.

Figure 1 Tilting furnace assembly drawing



Source: Babalola et al. (2012)

3 Materials and methods

The tilting furnace used in this work has an installed electrical blower of 600 W (230 V, 50 Hz, and 16,000 RPM) with flow rate capacity of 2.8 cbm/min. The fuel for the burning is diesel oil though used lubricating oil could also be used. However, used lubricating oils usually contain wear particles from bearings such as lead and other heavy metals, so adequate precautions must be in place to ensure that these do not contaminate the product or cause excessive emissions of these pollutants. The mixer motor is 1,200 W (220 V, 50 Hz) and adjustable revolution (0–800/1,950 RPM). The furnace was tested for functionality and was found to melt (25–750°C) 10 kg of aluminium within 20 minutes (Babalola et al., 2012). The same set up was used to produce aluminium matrix composite (AMC) by adding silicon carbide (SiC) particles into the aluminium melt. The mixing duration was about 3 minutes in all the 17 different samples developed (Babalola, 2015). The furnace has been tested for melting iron with melting point of 1,500°C.

Hence, it is can melt other metals with lower melting point to that of iron, that is; gold, aluminium, lead, magnesium, copper, tin et cetera.

The solar PV-system produces direct current (DC) electricity from solar radiation through the photovoltaic effect. The solar module in the PV-system is made up of several individual cells whose arrangement and number determines the amount energy produced by the PV-system (Abanda et al., 2016). In this work, a solar panel of 250 W was selected (see Table 1) to charge the battery within 2.4 hrs. If a lower capacity solar panel is used, the charging time would increase. A solar panel of 100 W will charge this system for 6 hrs. The charging time t_{CH} [equation (1)] is as follows:

$$t_{CH} = (b_{AH} * f_c) / p_W \quad \text{(a)}$$

where

b_{AH} battery capacity (AH)

p_W solar panel wattage (W)

f_C combined loss factor = 2.

The electrical energy from the PV panel was stored in 300 Ah deep cycle battery with the charging controlled with 20 A charge controller (see Table 2). The electrical power was supplied to the blower and mixer (stirrer) simultaneously from 1,440 W inverter (see Table 3). The diagrams of the setup used in this work are shown in Figures 2 and 3.

Table 1 Solar panel specifications

Descriptions	*Specifications*
Product type	250 W photovoltaic solar panel
Rated output voltage	37.5 V
Cell type	Monocrystalline silicon
Life time	25 years
Rated power (Pmax)	250 W
Current at Pmax (Irmp)	5.2 A
Voltage at Pmax (Vrmp)	48 V
Short circuit current (Isc)	5.63 A

Table 2 Charge controller specifications

Descriptions	*Specifications*
Model type	MPPT-type charge controller (F1224-30M)
System voltage	12 V / 24 V
Max battery capacity	800 Ah
Max efficiency	>98%
Max output current	30 A
Overcharge	14.7 V / 29.4 V (+/–) 1%
Over discharge	10.8 V / 21.6 (+/–) 0.3 V

Figure 2 Schematic diagram of the stand-alone PV system used in this work (see online version for colours)

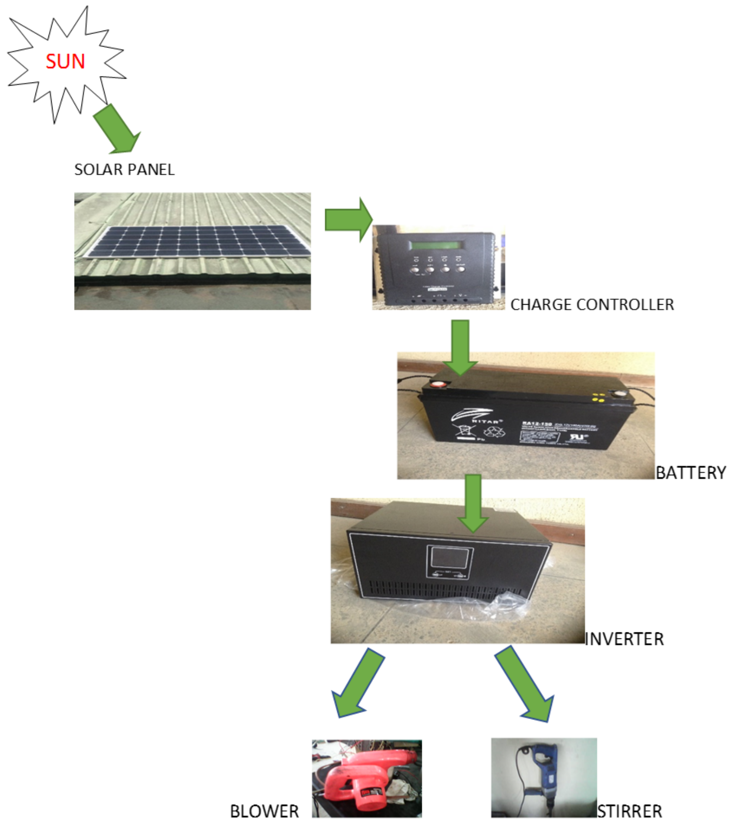


Table 3 Inverter specifications

Descriptions	*Specifications*
Rated voltage	24 V
DC input range	20.5 V – 29.5
Inverter output range	220 Vac / 230 Vac / 240 Vac
Mains AC output range	188 V – 245 Vac for 220 Vac
	198 V – 254 Vac for 230 Vac
	208 V – 264 Vac for 240 Vac
Frequency output	50 Hz / 60 Hz
Waveform	Pure sine wave
Power	1,440 W
Power factor	1
Inverter output frequency	Max 85% (resistive load)
Protective function	Overload, low battery, short circuit, over charge

Figure 3 Components of the stand-alone PV system used in this work (see online version for colours)

The drain test was carried out on the battery to determine how long it takes the battery to completely drain out or reach its cut off voltage of the inverter. The cut off voltage for the inverter is 20 V. The drain test of the battery is a function of voltage drop with time. The drain test was carried out on the battery using digital multi-metre and a digital stopwatch with blower and stirrer as load. Readings of the voltmeter and digital stopwatch were taken at interval of 3 minutes stating from zero second for 30 minutes. The results of voltage against time was plotted using Excel spreadsheet.

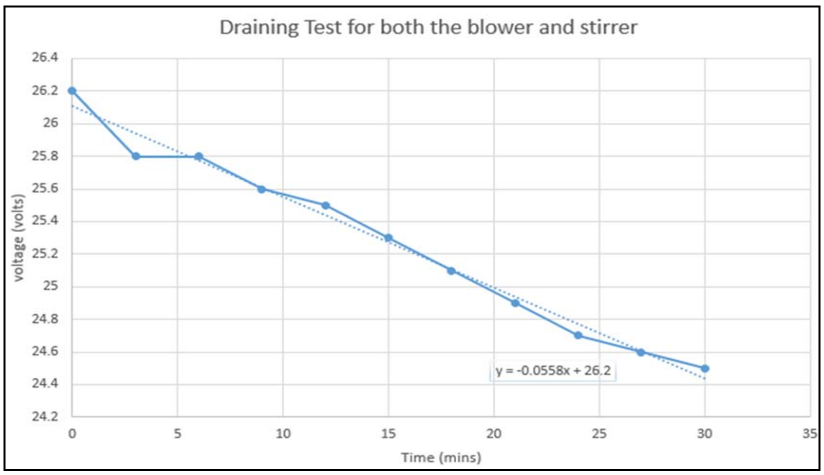
4 Result and discussion

The results from the drain test is shown in Table 4 and the plot (Figure 4) reveals a linear relationship between voltage and time of operation. An empirical relation, $V = -0.0588t + 26.6$ was obtained from the drain test, where V is the voltage of the battery and t is the time of operating both the blower and the stirrer. Now using the cut-off voltage of the inverter to be 20 volts, the drain time was estimated to be 105.44 minutes from the empirical equation. This is the worst scenario since actual smelting requires 20 minutes of blower operation including just 3 minutes of stirrer usage. At least, five smelting operations could be done without solar radiation.

Table 4 Results of drain test

Time (mins)	*Voltage (volts)*
0	26.2
3	25.8
6	25.8
9	25.6
12	25.5
15	25.3
18	25.1
21	24.9
24	24.7
27	24.6
30	24.5

Figure 4 Drain test using blower and the stirrer as load (see online version for colours)



5 Conclusions

A stand-alone photovoltaic system was used to generate the electrical energy for the stirrer and blower of a tilting furnace designed for melting iron, gold, aluminium, lead, magnesium, copper, tin et cetera and to produce metal matrix composites through liquid metallurgy routes. The tilting mechanism allows easy evacuation of the melt. With the PV system, the furnace could be set up in remote areas by SMEs. The battery functioned for at least 105 minutes without the solar panel. The use of solar energy reduces the amount of emission from the production process and hence more environmentally friendly.

Acknowledgements

The authors wish to gratefully acknowledge the funding provided by Covenant University, Ota, Nigeria.

References

Abanda, F.H., Manjia, M.B., Enongene, K.E., Tah, J.H.M. and Pettang, C. (2016) 'A feasibility study of a residential photovoltaic system in Cameroon', *Sustainable Energy Technologies and Assessments*, Vol. 17, No. 1, pp.38–49, doi.org/10.1016/j.seta.2016.08.002.

Babalola, P.O. (2015) *Development of Aluminium Matrix Composite (AMC) with Silicon Carbide Particles Using Stir Casting Method*, PhD thesis, pp.1–252, Covenant University, Ota, Nigeria.

Babalola, P.O., Inegbenebor A.O. and Bolu, C.A. (2012) 'Design and construction of tilting furnace for producing aluminium matrix composites', Paper presented at the *International Conference on Clean Technology and Contemporary Engineering Management-ICCEM*, Mechanical Engineering, Covenant University, Ota, Nigeria, pp.260–271.

Bhatti, A.R., Salam, Z. and Ashique, R.H. (2016) 'Electric vehicle charging using photovoltaic based microgrid for remote islands', *Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid*, *Energy Procedia,* Maldives, 19–21 April, Vol. 103, pp.213–218.

Castro, T.S., de Souza, T.M. and Silveira, J.L. (2017) 'Feasibility of electric vehicle: electricity by grid x photovoltaic energy', *Renewable and Sustainable Energy Reviews* Vol. 69, No. 1, pp.1077–1084, doi.org/10.1016/j.rser.2016.09.099.

Cucchiella, F., D'Adamo, I. and Gastaldi, M. (2016) 'Photovoltaic energy systems with battery storage for residential areas: an economic analysis', *Journal of Cleaner Production*, Vol. 131, No. 1, pp.460–474, doi.org/10.1016/j.jclepro.2016.04.157.

Ezzat, M.F. and Dincer, I. (2016) 'Development, analysis and assessment of a fuel cell and solar photovoltaic system powered vehicle', *Energy Conversion and Management*, Vol. 129, No. 1, pp.284–292, doi.org/10.1016/j.enconman.2016.10.025.

Huide, F., Xuxin, Z., Lei, M., Tao, Z., Qixing, W. and Hongyuan, S. (2017) 'A comparative study on three types of solar utilization technologies for buildings: photovoltaic, solar thermal and hybrid photovoltaic/thermal systems', *Energy Conversion and Management*, Vol. 140, No. 1, pp.1–13, doi.org/10.1016/j.enconman.2017.02.059.

Kaur, S., Dhillon, G.S., Sarma, S.J., Brar, S.K., Misra, K. and Oberoi, H.S. (2014) 'Waste biomass: a prospective renewable resource for development of bio-based economy/processes', in Brar, S.K., Dhillon, G.S. and Soccol C.R. (Eds.): *Biotransformation of Waste Biomass into High Value Biochemicals*, pp.3–28, Springer, London.

Madeti, S.R. and Singh, S.N. (2017) 'Monitoring system for photovoltaic plants: a review', *Renewable and Sustainable Energy Review*, Vol. 67, pp.1180–1207 [online] http://dx.doi.org/10.1016/j.rser.2016.09.088.

Matthews, V.O., Atayero, A.A. and Popoola, S.I. (2016) 'Development of a solar photovoltaic vulcanizing machine towards extreme poverty eradication in Africa', *Proceedings of the World Congress on Engineering and Computer Science*, WCECS 2016, 19–21 October, San Francisco, USA, Vol. 1.

Okoye, C.O. and Solyal, O. (2017) 'Optimal sizing of stand-alone photovoltaic systems in residential buildings', *Energy*, DOI: 10.1016/j.energy.2017.03.032.

Oyedepo, S.O. (2012) 'On energy for sustainable development in Nigeria', *Renewable and Sustainable Energy Reviews*, Vol. 16, No. 1, pp.2583–2598, doi:10.1016/j.rser.2012.02.010.

Popoola, S.I., Atayero, A.A., Matthews V.O. and Ajala, A.O. (2017) 'Solar photovoltaic automobile recognition system for smart-green access control using RFID and LoRa LPWAN technologies', *Journal of Engineering and Applied Sciences*, Vol. 12, No. 4, pp.913–919, ISSN: 1816-949X.

Romantchik, E., Ríos, E., Sánchez, E., López, I. and Sánchez, J.R. (2017) 'Determination of energy to be supplied by photovoltaic systems for fan-pad systems in cooling process of greenhouses', *Applied Thermal Engineering*, Vol. 114, No. 1, pp.1161–1168, doi.org/10.1016/j.applthermaleng.2016.10.011.

Sun, C., Sun, F. and Moura, S.J. (2016) 'Nonlinear predictive energy management of residential buildings with photovoltaics & batteries', *Journal of Power Sources*, Vol. 325, No. 1, pp.723–731, doi.org/10.1016/j.jpowsour.2016.06.076.

Tam, V.W.Y., Le, K.N., Zeng, S.X., Wang, X., Chethana, I.M. and Illankoon, S. (2016) 'Regenerative practice of using photovoltaic solar systems for residential dwellings: an empirical study in Australia', *Renewable and Sustainable Energy Reviews* [online] http://dx.doi.org/10.1016/j.rser.2016.10.040.

Vieira, F.M., Moura, P.S. and de Almeida, A.T. (2017) 'Energy storage system for self-consumption of photovoltaic energy in residential zero energy buildings', *Renew. Energy*, Vol. 103, No. 1, pp.308–320, doi.org/10.1016/j.renene.2016.11.048.

Xue, J. (2017) 'Photovoltaic agriculture – new opportunity for photovoltaic applications in China', *Renewable and Sustainable Energy Reviews*, Vol. 73, No. 1, pp.1–9, doi.org/10.1016/j.rser.2017.01.098.

Zhang, Y., Lundblad, A., Campana, P.E. and Yan, J. (2016) 'Employing battery storage to increase photovoltaic self-sufficiency in a residential building of Sweden', *Energy Procedia*, Vol. 88, pp.455–461.