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Improving Electricity Generation in Nigeria Using Weight of Trucks: A Case Study of Dangote Cement Plant, Ibese, Ogun State

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Abstract—*Generation of sufficient electric power at a relatively lesser cost is very key to the development and sustainability of any organisation/industry in a society. Owing to the fact that constant electricity is needed by Dangote Cement Plant, Ibese. Ogun State to sustain its non-stop operation, huge amount of money is spent on fuel by the industry to run the power plant. An average of three hundred and fifty (350) loaded trucks with a net weight of sixty (60) tons each, and a total of 21,000 tons are being dispatched from the plant on a daily basis. This huge amount of weight could therefore be harnessed and utilised by converting it to electrical energy by the use of hydraulic speed bumps in combination with hydraulic accumulators, hydraulic pump, hydraulic turbine and generator. It is estimated that an average of 5.87MW of electric power could be generated per day. The system has the ability to recycle the hydraulic fluid which conveys the kinetic energy to drive the hydraulic turbine. This in effect will drastically reduce the cost of producing electric energy by the industry.*

Keywords—*Accumulator, Bump, Cost-reduction, Electricity, Generator, Turbine*

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I. Introduction

One of the criteria to ascertain the level of development of a nation or organization is the availability and efficiency of its electric power system. Industrialized and developed nations like U.S.A. has 1,039,000MW installed capacity; China has 1,146,000MW installed capacity; Brazil: 133,7000MW, South Africa: 47,902MW [1]. In the case of Asian Tigers: Singapore with a population of 5,805,958 has about 14,000MW installed capacity of electric power as at 2018. Hong Kong had a total installed capacity of 12,644MW with a population of 7,439,688 as at 2006. Taiwan has a total installed capacity of 49,000MW with a population of 24,000,000 as at 2018. South Korea has a total installed capacity of 94,350MW with a population of 50,982,212 as at 2018. Conversely, Nigeria has total installed capacity of 12,310MW for a population of 198,000,000 inhabitants with a national demand of about 42,000MW [5], [6]. Even at that, Nigeria still supplies about seven percent of electric energy generated per annum to both Benin and Niger Republics [3]. This cross-border transaction must take place; otherwise the two countries would dam the River Niger which is the major source of hydropower in Nigeria [1], [2].

Resources Electricity in Nigeria

Recent studies revealed that there are about thirty (30) Power stations in Nigeria. The combine installed capacity of the various conventional energy sources was estimated to be 13,000MW. Unfortunately, the highest amount of electric power generated by the year 2029 was 6,238MW [12]. The government owned Transmission Company of Nigeria (TCN) has a wheeling capacity of about 7,000 MW. However, between 3,000 MW to 5,000 have been estimated as the handling capacity of the distribution companies (DISCOs) [11]. to Sources of electric power in Nigeria could be categorized into renewable and non-renewable energy[8].

Renewable Energy

Renewable energy sources are sources which are naturally reproduced and could be harnessed by the suitable equipment or devices for the purpose of generating electricity or conversion into the desired form. Examples of renewable energy sources available in Nigeria are: Solar, Geothermal, Tidal, wind, Biomass etc. [8]

Non-renewable or Conventional Energy

The major sources of electric energy in Nigeria is conventional sources such as Diesel, Natural gas (methane), fuel, coal etc. [10]. This is illustrated in table 1.0 below.

Table 1.0: Electric power generating stations, locations and their respective installed caapacity.

S/N	NAME OF STATION	TYPE	LOCATION	INSTALLED CAPACITY (MW)
1	Jebba power station	hydro	Niger state	540
2	Kainji power station	hydro	Niger state	800
3	Kano power station	hydro	Kano	100
4	Dadin Kowa power station,	hydro	Gombe state	40
5	Azura power station	Gas turbine	Edo state	450
6	Itobe power station	Circulating Fluidized bed technology	Kogi State	1200
7	Sapele power station(1)	Gas fired steam turbine,	Delta state	1020
8	Sapele power station (2)	Simple cycle gas turbine	Delta state	450
9	Transcorp Ughelli power station	simple cycle gas turbine	Delta state	900
10	Ibom power station	combined cycle gas turbine	Ikot Abasi, Akwa Ibom State	191
11	Omotosho power station I	simple gas turbine	Ondo state	336
12	Omotosho power station II	simple gas turbine	Ondo State	450
13	Omoku power station I	simple cycle gas turbine	Rivers state	150
14	Omoku power station II	simple cycle gas turbine	Rivers State,	225
15	Olorunsogo power station I	simple cycle gas turbine,	Oyo State	336
16	Olorunsogo power station II	combined cycle gas turbine,	Oyo State	675
17	Okpai power station	combined cycle gas turbine	Delta state	480
18	Kudenda power plant	Thermal gas	Kaduna State	215
19	Egbema power station	Simple cycle gas turbine,	Imo State	338
20	Egbin power station	gas fired steam turbine	Lagos State	1320
21	Geregu power station I	simple cycle gas turbine	Kogi state	414
22	Geregu power station II	simple cycle steam turbine	Kogi state	434
23	Ibom power station	simple cycle gas turbine	Akwa Ibom State	190
24	Ihovbor power station	simple cycle gas turbine	Edo State	450
25	AES BARGE power station	simple cycle gas turbine	Lagos State	270
26	ABA power station	simple cycle gas turbine	Abia State,	140
27	AFAM power station V-V	combined cycle gas turbine,	Rivers state,	726
28	AFAM power station VI	combine cycle gas turbine	Rivers State	624
29	ALAOJI power station	combined cycle gas turbine,	Abia state,	1074
30	CALABAR power station	simple cycle gas turbine	Cross River State	561

Dangote Cement Plant, Ibese, Ogun State is generating 203MW of electricity to meet her operational demand by using Bi-Fuel (Gas and Coal) [7]. In this research work, suitable combination of hydraulic accumulators, hydraulic bumps, hydraulic turbine and generator was used to design a system to utilize the weight of trucks by converting it to electric power. Hydraulic accumulators are mechanical energy storage devices that are similar to rechargeable batteries in electrical systems. They receive, store and transfer energy in the form of pressurized fluid and are essentially engaged to enhance the efficiency of hydraulic systems An average of three hundred and fifty (350) loaded trucks with a net weight of sixty (60) tons each, and a total of 21,000 tons are being dispatched from the plant on a daily basis by Dangote Cement Plant Ibese, Ogun State. Nigeria. It is estimated that an average of 5.87MW of electric power could be generated per day. The system has the ability to recycle the hydraulic fluid which conveys the kinetic energy to drive the hydraulic turbine. This will however, drastically reduce the cost of producing electric energy by the industry.

II. Methodology

Hydraulic bumps were installed on a road at intervals for trucks to pass over. Figure 1.1 below illustrates the block diagram of the power plant under consideration.

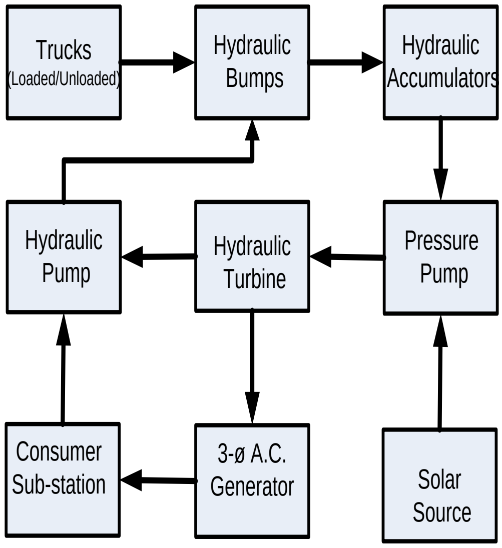

Fig. 1.1: A block diagram of electric power plant using weight of trucks

When a truck passes over a bump, the weight (force in Newton) of truck is converted to kinetic energy which is conveyed by the hydraulic fluid to the hydraulic accumulator as expressed in Work-Energy theorem below:
Force = Weight .... (1)
ma = mg (N) .... (2)
Where, m = mass of the trucks (Kg) a = acceleration in (m/s^2) and g = acceleration due to gravity in (m/s^2)
Work done = force x distance .... (3)
= weight x distance .... (4)
But, force = pressure x cross sectional area of the pipe ... . (5)
Substituting Eq. (5) in (3), gives; Work done = pressure x cross-sectional area x distance (Note: volume = cross-sectional area x distance) Work done = pressure x volume.. (6)
The above equations can be mathematically expressed as:

$W_{net} = \int F_{max}.dx$

But $F_{max} = m.\frac{dv}{dt} = m.\frac{dv}{dx}.\frac{dx}{dt} = mv.\frac{dv}{dx}$

Thus Eq(1) becomes :

$W_{net} = \int mv\,.\frac{dv}{dx}.\,dx$

$W_{net} = \int_{v_i}^{v_f} mv\,.\,dv$

$W_{net} = \frac{1}{2}m.\left[v^2\right]_{v_i}^{v_f} = \frac{1}{2}m.\left[v_f^2 - v_i^2\right]$

Note: KE = $\frac{1}{2}mv^2$

Hence:

$W_{net} = KE_f - KE_i = \Delta KE$

Essentially, an Electric Power Plant using weight of trucks consists of: (i) trucks - loaded/unloaded (ii) hydraulic bumps (iii) hydraulic accumulators (iv) pressure pump (v) hydraulic turbine (v) hydraulic pump (vi) solar source (vii) 3-phase A.C. generator and (viii) Consumer sub-station. Fig 1.1 shows a block diagram of the Electric Power Plant using weight of trucks. Kinetic energy is stored in the hydraulic accumulator. The hydraulic accumulator is an energy storage device analogous to the deep-cycle battery in solar power system. The hydraulic accumulator discharges stored hydraulic fluid to the pressure pump. The pressure pump is powered with an independent solar power source. The pressure pump increases the pressure of the fluid from hydraulic accumulators hence, the kinetic energy of the hydraulic fluid. Thereafter, the pressure pump supplies the high-pressured fluid to the hydraulic turbine, which in-turn rotates the prime mover of the generator and thus producing electric power as the output. The hydraulic pump which is powered from the consumer sub-station is connected to the outlet of the hydraulic turbine and pumps the fluid back to the hydraulic bumps. The cycle repeats itself continuously; hence it is very efficient in operation. Hydraulic accumulators are mechanical energy storage devices. In a similar manner to rechargeable batteries in electrical systems, they receive, store and discharge energy in the form of pressurized fluid and are mostly used to improve hydraulic-system efficiency [3]. An accumulator is a pressure vessel that holds hydraulic fluid and a compressible gas, typically nitrogen. The casing is made of metallic materials such as: steel, stainless steel, aluminum, titanium and fiber-reinforced composites. Inside is a moveable or flexible barrier - usually a piston or rubber bladder that separates the oil from the gas. Three common types of hydraulic accumulators are available namely: bladder, piston and diaphragm hydraulic accumulators. Out of these three types, experts consider bladder accumulators as the best universal purpose units and therefore used in this work. Bladder accumulators typically have large ports that permit rapid fluid discharge to ensure that the accumulators are relatively insensitive to dirt and contamination. A general rule is to mount bladder accumulators vertically, although they can also be mounted on their sides in low-cycle applications. Bladder accumulators are often developed at a four is to one pressure ratio which is the highest pressure to gas-charged pressure which is designed to guide the bladder from extreme disturbance and or material stretching. Bladder accumulators come in a wide range of standard sizes, and good response characteristics make them well suited for shock applications. Depending on the design, a bladder can be easily replaced in the event of failure or damage. Accumulators contain pressurized energy which could be used to support the flow of the hydraulic by the pump, thereby enhancing system responses and to serve as a back-up at the event of blackout. Accumulators could also augment the amount of fluid leakages.

Kaplan turbine: is an axial-flow turbine which has an advantage of operating at low head as compared with Francis turbine. It is more preferable than other types of hydro turbine due to its ability to operate at variable flow rates [4]. Kaplan’s are relative expensive, they are the turbine of choice for lower head sites with high flow rates. Typically, they are used on sites with net heads from 1.5 to 20m and peak flow rates from $3m^3/s$ to $30m^3/s$.

Hydraulic generator: this is an electromechanical machine which converts the kinetic energy contained in the moving hydraulic to electrical energy based on the principle of machine which converts the kinetic energy contained in the moving hydraulic to electrical energy based on the principle of electromagnetic induction. It does so at a high efficiency of approximately 96%. Fig. 6.0 A three-phase hydraulic generator

Hydraulic pumps: is a mechanical machine which serves as a pressure booster in a hydraulic drive system. The most common types are hydrostatic and hydrodynamic depending on the area of application, with the former been a positive displacement while the later been fixed displacement pump. The operation of hydraulic pump is such that it produces a vacuum at the pump inlet, thereby pushing the hydraulic to flow from the reservoir into the inlet line. The fluid is conveyed to the outlet and thereafter to the hydraulic system by the mechanical action of the pump.

III. Result and Discussion

Table2.0: Relationship between mechanical power and electric power

S/N	No. of Trucks	Work Done (J)	Mech. Power Produced per Day (W)	Electric Power Produced per Day (W)
1	35	$06.34x10^6$	73.38	58.70
2	70	$12.68x10^6$	146.76	117.41
3	105	$19.02x10^6$	220.14	176.11
4	140	$25.35x10^6$	293.40	234.72
5	175	$31.69x10^6$	366.78	293.42
6	210	$38.03x10^6$	440.16	352.13
7	245	$44.37x10^6$	513.54	410.83
8	280	$50.71x10^6$	586.92	469.54
9	315	$57.05x10^6$	660.30	528.24
10	350	$63.39x10^6$	733.68	586.94

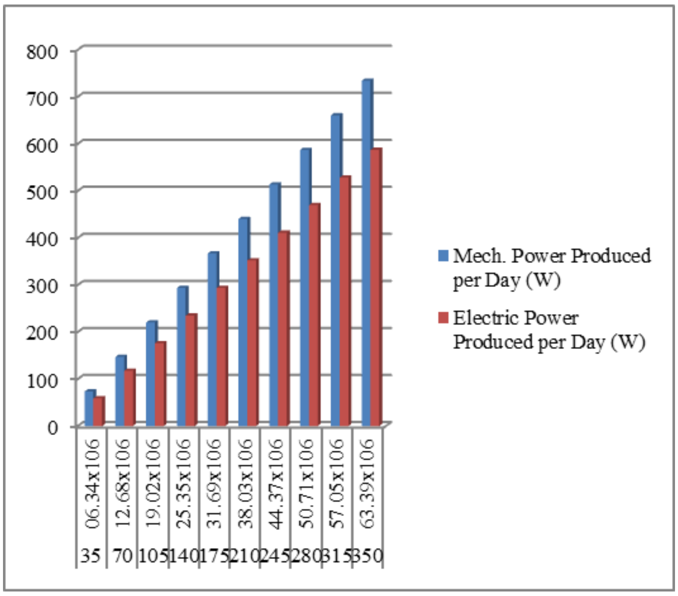

Fig. 2.0: A bar chart showing the relationship between mech. Power and electric power.

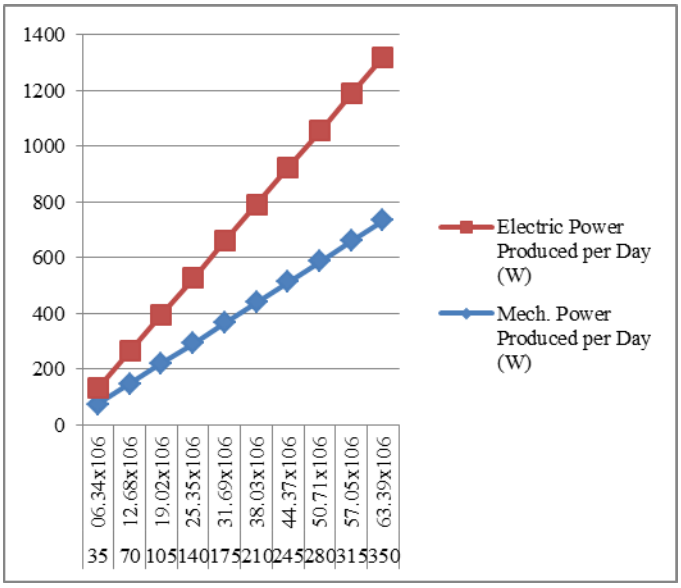

Fig. 3.0: A graph showing the relationship between mech. Power and electric power

An unloaded Dangote trucks has a weight of 15tons, while the loaded one has a net weight of 60 tons. One ton is approximately 1000kg (i.e. 60tons = 60,000kg). Thus 60 tons = 1000 x 60 = 60,000**kg**. Acceleration due to gravity, g = 9.9**m/s^2**. The net weight of one loaded truck = mg = 60,000 x 9.8 = 588,000 Newton. If the distance moved by the force (weight) is one foot (0.305**m**); then the work done by one loaded truck on a single hydraulic bump is given by; W = weight x distance = 588,000 x 0.305 = 181,104**J** Hence, the work done by 350 trucks on a single bump is; W = 350 x 181,104 = 63,386,400**J** = 63.3864**MJ.** The mechanical power, Pw produced per day by 350 loaded trucks on a single hydraulic bump is given by; Pw = (workdone)/(time taken) = 63,386,400/60x60x24 = 63,386,400/86,400 = 733.64**W** Accordingly, the power produced in a day when 10 bumps are installed is: Pw = 733.64x10 = 7336.4**W** = 7.34**KW.**

Pressure = workdone/volume, the Volume V, of the hydraulic bump = length x breath x height.

For the bump of which has length = 6**m**, breath = 0.61**m (2ft**) and the height = 0.305m (1ft); then volume V = 6 x 0.61x 0.305 = 1.12**m^3**.

Therefore, total pressure generated is given by; Pressure = workdone/volume = 63,386,400/1.12 = 56,595,000 **N/m^2**. If a pressure pump is used to raise the pressure P, of the fluid by 1000 times; P = 56,595,000 x 1000 = 56.6x109**N/m^2** . Recall that at a constant volume, pressure is directly proportional to work done, that is, W = PV. Where, V is a constant. If the pressure of the hydraulic fluid is raised from 5.66x107**N/m^2** to 56.6x109N/m^2; this implies that the work done will also increase by times 1000. That is, W = 63,386,400 x 1000

= 63.39x109 **J**.The power produced by a single bump when 350 loaded trucks of net mass of 21,000 tons is applied per day will be; Pw = 63.39x109/86,400 = 733,638.89**W** = 733.64 **KW**. If the number of hydraulic bumps is increased to 100, the net power produced is: Pw = 733.64 x 10 = 7,336.4**KW** = 7.34 **MW** If 20% power loss is assumed while converting mechanical power to electrical power by the generator (for simulation purposes). That is, 80% conversion efficiency. Therefore, power loss: P_L = 7.34 x109 x20/100 = 1.467x109 **W** Electrical Power, $P_{E,}$ produced at the output = mechanical power, P_w minus the power loss, PL. It is given by: P_E = Pw – P_L. That is; = 7.34x109 - 1.467x109 = 5.87 MW Therefore, the Electrical Power P_E, produced = **5.87MW**.

IV. Conclusion

Conversion of weight of trucks to useful (electrical) energy has been demonstrated. It is clear that the huge amount of weight dissipated by 350 loaded trucks being dispatched from Dangote Cement Plant, Ibese, Ogun State on a daily basis can be harnessed and converted to electric power. With 100 numbers of 1.12m3 hydraulic bumps, 5.87MW of electric power could be generated. If ₦25 is assumed to be the cost of 1KWH, then the cost of generating 5.87MW is ₦3.52million per hour. That is, ₦3.52million per hour could be saved. This huge amount of money saved, can be used to to provide employment opportunities for the youths. Hence, curbing unemployment and insecurity in Nigeria.

V. Recommendations

With little improvement and further work on the design, this research work can be implemented in Dangote Cement Plant Ibese, Ogun State. Nigeria. This research work can also be implemented in Apapa Lagos State, LAFARGE Cement Plant in Ewekoro Ogun State, Bus parks, as well as any organisation that uses an array of large number of trucks. This will tremendously improve the power generation in Nigeria.

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