

## PAPER 110 – DESIGN AND SIMULATION OF HYBRID POWER SUPPLY FOR RESIDENTIAL CONSUMER

D. E. Abah<sup>1\*</sup>, N. A. Iiyasu<sup>1</sup>, A. J. Aliyu<sup>1</sup>, A. Kabir<sup>2</sup>

<sup>1</sup>Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria.

<sup>2</sup>Department of Electrical and Electronics Engineering, Federal Polytechnic Kaura Namoda.

Email: [deabah@abu.edu.ng](mailto:deabah@abu.edu.ng)

### **ABSTRACT**

Hybrid Power System (HPS) is a combination of different renewable resources such as wind, solar, biomass, hydrogen fuel, hydro, with fossil fuel powered diesel generator to provide electric power. The objective of this work is to propose a methodology for designing a stand-alone hybrid PV/diesel/battery system minimizing the Cost of Energy (COE) and the CO<sub>2</sub> emission using HOMER (Hybrid Optimization of Multiple Electric Renewables) for a residence at Marcus Poli Estate Gwarinpa, Abuja, Nigeria. The capital cost, cost of energy, Net Present Cost (NPC) for different types of resources are determined from the load demand and optimized configuration of hybrid system are obtained. The analysis results show that, among five hybrid systems for supplying electrical requirements, the most economical is the PV - diesel -battery hybrid system, which has a total net present cost of US\$118,771 and a cost of energy of US\$0.340/kWh. The action plan is formed on the basis of cost-effective modelling that is minimization of energy production cost in a near future.

**KEYWORDS:** Cost of Energy; Hybrid Power System; MPPT; Net present Cost; Power Demand; Renewable Energy.

### **1. INTRODUCTION**

In recent era there is a great scope for advancement in power generation considering environment friendly technology such as renewable energy technology is becoming, as technically viable and environmentally friendly. Around the world, effort is being made to study the viability of renewable energy incorporated hybrid system as alternative of diesel generator. The hybrid energy system generally works with primary renewable source in parallel combination of a standby secondary non-renewable module and storage unit (Ali *et al.*, 2017).

Main drawbacks of the standalone system considering solar as well as wind energy is the energy fluctuation, resulting in intermittent delivery of power and causing problems if reliable and continuous supply is required benefits. So, such types of problems can be overcome by the use of standalone hybrid systems. A hybrid power system can be defined as a combination of different source of energy, but complementary energy generation system can be provided by renewable energy or mixed (RES- with a backup of diesel generator set). Hybrid systems provides the better features of each energy resources as compared to conventional sources and also provide “grid-quality” electricity, with a power range of kilowatt to several hundred kilowatts (Iqbal & Khan, 2017; Zubo *et al.*, 2018). Recent increase in power system complexity, rapid increased in energy demand, the requirement of secured and reliable power system, and power supply efficiency have made Hybrid Energy Systems (HES) development a major focus of the recent.

### **2 THEORETICAL ANALYSES**

This section introduces the fundamental concepts relevant to this research. The review of literature is very important in establishing the basis and contemporaries of any research.

#### **2.1 Component Modelling**

The component of the system as discussed in previous sections consist of photovoltaic generator system, diesel generator system, grid, transmission system, control and communication system. Therefore, this section reviews the modelling techniques of the involving component of the Smart Grid (SG) technology.

##### **2.1.1 Photovoltaic generator System (PGS)**

PV farms are continuously being developing all over the world, usually having capacity up to the ranges of 1 MW to 500 MW (Singh *et al.*, 2016). These PV farms could stand an alternative source of energy and improving the energy challenges of consumers. Grid connected PV system consist mainly of mechanical and electronic component.

##### **2.1.2 PV System Module**

Solar cell is an electronics component used for conversion of photon energy into pollution-free and green electric energy. Basically, the connection of the device in series and parallel pattern forms a PV module. Furthermore, to build PV arrays these modules are coupled in series and parallel forms to generate clean and green electric energy

(Iqbal & Khan, 2017). The solar cell process of capturing and converting sunlight energy into electricity is generally referred as photovoltaic conversion (Zubo *et al.*, 2018).

### 2.1.3 MPPT

Maximum power point tracking (MPPT) is a control algorithm implanted in a DC–DC electronic power system converter with the function to extract maximum power from a PV array system. The main purpose of MPPT technique is to guarantee that the maximum power extracted from a PV system matches the optimum value of the power and voltage characteristic curve under sunlight irradiation (G) and temperature (T) variations. The function of the MPPT tracking algorithms is to latch the converter system operating voltage and current to the maximum power point (MPP) of the PV array.

### 2.1.4 Inverter System

MG as a novel technology that could immensely help to increase the reliability, resiliency and efficiency of power system grid network. Though, many challenging issues surrounding microgrid technology development are in existence and want to be carefully addressed in order to ensure the proper implementation and operation of the MG systems (Lasseter *et al.*, 2003; Rocabert *et al.*, 2012). One of those challenges is the stability of those systems throughout their smooth operation (Zamani-Gargari *et al.*, 2018). The requirement to run AC Loads on solar energy leads necessitate the design of Solar Power Inverter system.

### 2.1.6 Dynamic Load

Ideally, Mega size electric power is generated in three phases, the three phases are inherently desired to be balance, even though attaining balance mode is difficult, but something close to the balance mode (symmetry) is always achievable (Amuta, 2019). An electric power system can be described to be symmetrical if the supply magnitudes are symmetrically equal and phase angles of the respective phases are spaced at an angle of 120 electrical degrees, otherwise the power systems network are termed asymmetrical. Research works on load modelling are significant in the sense that, power system operators require knowledge of the system dynamics under normal and faults operating conditions for decision making with regards to system stability margin and subsequently, control and or protection. Recently, different types of loads are continuously modelled and developed. dynamic loads are time dependent and are largely represented by Induction Motors (IMs) (Kontis *et al.*, 2017). There exist two approaches of load modeling in the literature namely; component based and measurement-based approaches (Dong *et al.*, 2012; Han, 2020; Saviozzi *et al.*, 2018; Sharafi *et al.*, 2019). The Component based load modeling requires knowledge of individual loads, acquisition of relationship between the voltage and or frequency dependency on real and reactive power of each component and then cumulate the results for all the components connected to the network.

## 3. MATERIALS AND METHODS

In this section, detailed procedures, methods and materials used in achieving the aim and objectives of this research are discussed.

### 3.1 Models of Hybrid power system Component

Electricity has been around us for centuries, growing and changing day by day. Without electricity the world would have not been the same. The human relies on electricity to be always available and to perform its functions. Usage of electricity has been increased every year since 1949. Not only has electricity usage been rapidly increasing, energy cost is rising and energy possibility is decreasing. With this consecutive growth in electricity usage as well as in its cost, new and unique methods of producing electricity are being developed constantly. In this work, the energy sources considered are utility grid, diesel generator, and PV system.

### 3.2 Active PV Model

The mathematical description of PV cell has been studied over decades (Singh *et al.*, 2016). The electrical circuit representation of the PV cell model, consisting of a photocurrent, diode, parallel resistor (leakage current) and a series resistor; is as shown in Figure 1. Based on PV cell circuit and Kirchhoff's circuit laws, the PV current can be modelled as in the following Equation 1.

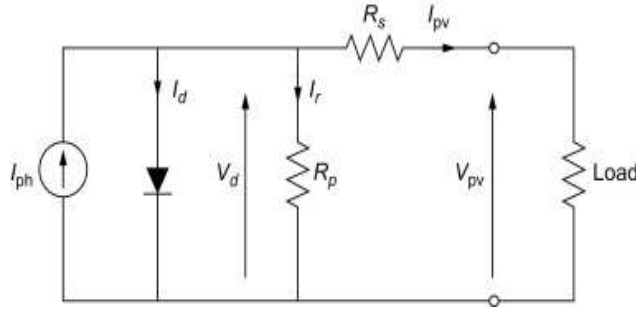


Figure 1: PV Model Electrical equivalent circuit

$$I_{pv} = I_{ph} - I_d - I_p = I_{ph} - I_0 \left( e^{\frac{V_{pv} + R_s I_{pv}}{n_s V_t Q_d}} - 1 \right) \quad (1)$$

Where;  $V_{pv}$  = PV- module Voltage,  $I_{pv}$  = PV Module Current,  $I_{ph}$  = Light current in (A),  $I_0$  = Diode reverse saturation current,  $Q_d$  = Diode idealistic factor,  $R_p$  = Shun Resistance,  $R_s$  = series resistance,  $n_s$  = number of cells,  $V_t = \frac{KT_c}{q}$  is the thermal voltage (V),  $k$  is Boltzmann's constant,  $T_c$  is the cell temperature, and  $q$  is the charge of an electron respectively.

### 3.3 Inverter System

Inverter system is an electrical device with related electronic components used to convert DC power into AC power within designed frequency and voltage magnitude. In system of microgrids architecture, an inverter system function to interfaces the DC sources of a renewable energy system to AC systems where the loads and utility grid are coupled. Technically, the inverter system is an important component in the microgrid system through which the voltage, frequency, active and reactive power can be controlled and stabilized. A typical three phase inverter system for PV interfacing to grid is as shown in figure 2.

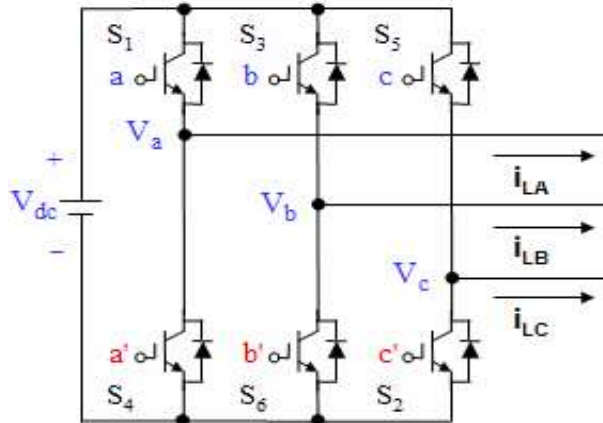


Figure 2: Inverter System Equivalent Circuit

The equivalent circuit system consists of three single phase inverter system cascaded together. The system operates like a single-phase inverter system but with 120° delay in the gating signals of each arm with respect to others. This is done to obtain a balanced three phase voltage from the output of the system. The technique is to controlled the operation of the transistor and diodes in the inverter circuit provided in any arm two switches are not ON or OFF simultaneously. The space vector equation representing this type of inverter can be expressed as in Equation 2.

$$V = \frac{2}{3} (V_a + aV_b + a^2V_c) \quad (2)$$

Moreover, this space vector formulation can be applied to both delta and star connected loads

Let Assume a star connected load, the total phase voltages at the star load for both balanced and unbalanced conditions is zero.

$$V_a + V_b + V_c = 0 \quad (3)$$

While, the phase voltage at the load point of coupling can be computed using Equation 4

$$V_i = V_j - V_{nk} \quad (4)$$

where  $i = a, b, c, j = A, B, C$  and  $n$  is the neutral point at the load point of interface  $k$  is the negative rail of the dc bus in the inverter Now, from Equation 4,  $V_{nk}$  can be expressed in terms of voltages at A, B and C as:

$$V_{nk} = \frac{V_{dc}}{3} (a^* + b^* + c^*) \quad (5)$$

Hence, the connection between the switching variable vectors  $a^*, b^*, c^*$  and phase to neutral output voltages vector can be mathematically expressed as:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a^* \\ b^* \\ c^* \end{bmatrix} \quad (6)$$

While the phase-to-phase voltage can be computed as in Equation 7

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \frac{V_{dc}}{1} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} a^* \\ b^* \\ c^* \end{bmatrix} \quad (7)$$

### 3.4 Utility Grid

To simulate microgrid in grid-connected mode, the grid side can be technically modelled as a three-phase power source, that is connected to distribution network lines through a step-down transformer (Craig et al., 2016).

#### 3.5 Diesel Generator Model

Diesel generators are mainly used for off-grid supply, low installed capacity, high shaft efficiency, suitable for start-stop operation and high exhaust heat which are some advantages of diesel generator. In this work, the diesel generator is used as a standby power system. It is switched ON only when PV source is not able to meet the load demand. In this condition, a control system management block developed activate the selector switch automatically to alternative source of energy. The diesel generator is modelled to feed a load of 24kw (30kVA).

## 4. RESULTS AND DISCUSSION

This chapter provides the detailed results and discussion of the analysis carried out based on the theoretical concepts in the preceding chapters are presented.

### 4.1 Load Profile

**The village considered to be electrified by Hybrid Energy Source is a residential building at Graceland, Zaria. The load profile of the residential was obtain from a survey as shown in Table 1.**

Table 1: Electrical energy utilization data in kWh/day

Equipment	No.	Watt (W)	Total Power (W)	Time (Hr)	Energy (Wh)	Kwh
Fan	4	75	300	10	3000	3
AC	4	1500	6000	5	30000	30
Fridge	2	250	500	24	12000	12
Tv	2	75	150	9	1350	1.35
Pressing Iron	1	2000	2000	2	4000	4
Electric Cooker	1	6000	6000	2	12000	12
Decoder	2	150	300	9	2700	2.7
Laptop	2	78	156	3	468	0.468
Sound System	1	100	100	9	900	0.9
Light	25	26	650	10	6500	6.5
Toaster Machine	1	1200	1200	1	1200	1.2
<b>Total</b>			17356			<b>74.118</b>

The total load obtained from the residence per day was calculated to be **74.118kWh** and the daily load profile is shown in the Figure 3.

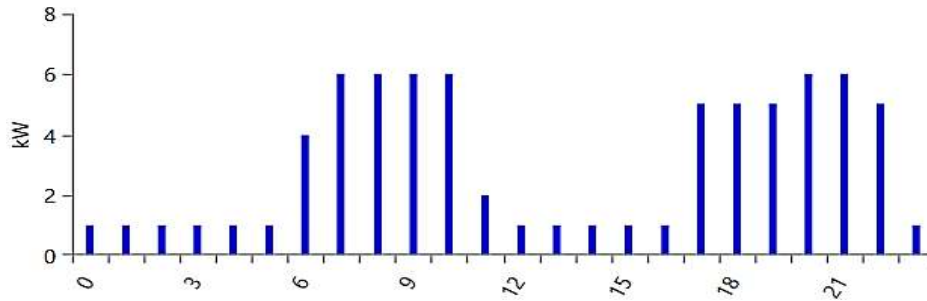


Figure 3: Daily Load profile

#### 4.2 Resources assessment

We have considered sun powered, converter, battery and bio-diesel assets. The sun-based asset utilized Graceland, Zaria at  $9^{\circ} 4.3'N$  and  $7^{\circ} 27.8'E$  was taken from NASA Surface Meteorology and Solar Energy site. The yearly normal sunlight-based radiation was scaled to be **4.93 kWh/m<sup>2</sup>/Day** and the normal clearness record was observed to be **0.483**. The sun-based radiation is accessible consistently; along these lines, a lot of PV power yield can be acquired is shown in Figure 4.

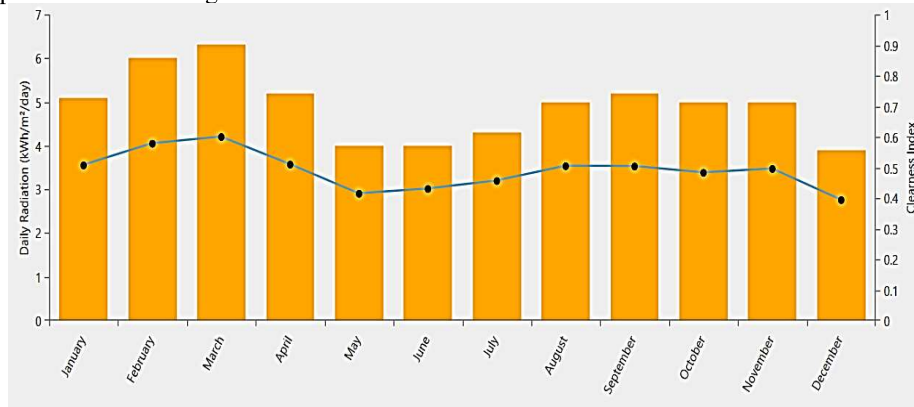


Figure 4: Solar radiation with clearness index

#### 4.3 Complete System Model

The complete system model is depicted in Figure 5 showing the integration of all the system component and the control techniques deployed. The control strategy deployed is a combination of logic gates. The system is made to operate in two modes, the islanded mode and the grid connected mode.

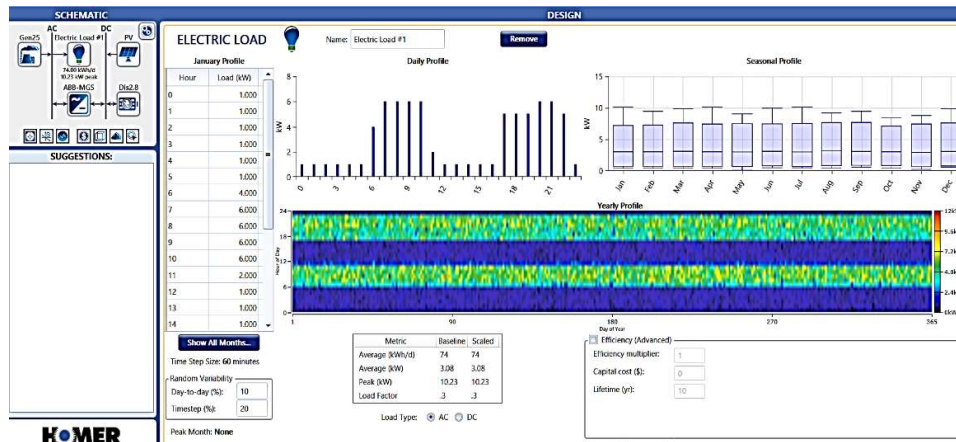


Figure 5: Complete System overview

#### 4.4 Hybrid System Design and Analysis

In this work, we have considered a combination of the following technologies, namely solar PV systems, batteries, system converters and a bio-diesel generator for back-up. Figure 6 shows a schematic system configuration diagram. Generally, an ordinary move down diesel generator (DG) is utilized to supplement the renewable energy (RE) framework for pinnacle loads and amid poor asset periods. In this work, a bio-diesel generator is utilized in making the entire framework a clean and carbon impartial framework, with the end goal of power era as well as for working successfully towards greenhouse gases (GHG) outflows moderation by not blazing any fossil fuels.

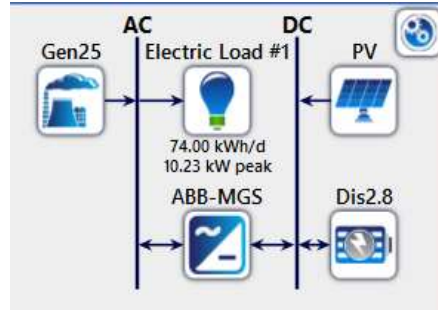


Figure 6: Schematic for the Hybrid Power system (HPS)

#### 4.5 Optimization results

HOMER simulates system configurations with all of the combinations of components available in HOMER. The input data are analysed, characterized, and tabulated systematically so as to determine the most economic hybrid system that are proposed in this work. The PV-generator-battery-system converter hybrid system is the most economic system among the thousands of PV-generator-battery-system converter hybrid systems which were analysed with the HOMER software. A comparison of this system with a chosen representative of each of the systems is provided in table 2. The strategy taken in this simulation is to ensure the energy generator provide enough energy to meet the demand. The results in table.2 indicate that the PV-battery-system converter is the most economic system among the five selected systems with a renewable factor of 100%. The system has a cost of energy (COE) of **US\$0.340/kWh** and net present cost (NPC) of **US\$118,771**. A PV-generator-battery-system converter is the second economic system for supplying the electrical energy demands for the resident. The COE and NPC of the system are **US\$0.411/kWh** and **US\$143,616** respectively. **The total simulating time step is 60 minutes. The analysis of the renewable energy resources data has been carried out using HOMER software.**

Table 2: Comparison of various hybrid power system

Architecture							Cost				
PV (kW)	Gen25 (kW)	Dis2.8 (kW)	ABB-MGS (kW)	Dispatch	COE (\$)	NPC (\$)	Operating cost (\$/yr)	Initial capital (\$)	Ren Frac (%)		
15.9		51	20.0	CC	\$0.340	\$118,771	\$2,343	\$88,489	100		
15.4	25.0	51	20.0	LF	\$0.411	\$143,616	\$1,996	\$117,816	99.9		
	25.0	45	40.0	CC	\$1.85	\$646,967	\$38,466	\$149,700	0		
199	25.0		20.0	CC	\$5.37	\$1.88M	\$118,127	\$349,475	0		
	25.0			CC	\$7.92	\$2.76M	\$211,489	\$30,000	0		

## 5. CONCLUSIONS

The plenteous energy available in nature can be harnessed and utilized to provide source of electricity that is more sustainable than fossil fuels. Access to electricity is particularly important concern for people without access to the electricity grid. The economic feasibility of hybrid power systems integrating renewable energy to meet the load requirements of a residence in Marcus Poli Estate Gwarinpa, Abuja, Nigeria has been successfully investigated.

Using HOMER software for optimization, five different systems are proposed as somewhat optimal. For the proposed systems the following conclusions are drawn:

- i. The most economic hybrid system is the solar pv-battery-power converter, with a net present cost (NPC) of **US\$118,771** and a cost of energy (COE) of **US\$0.340/kWh**.
  - ii. The second most economic hybrid system is the pv-diesel generator- battery-power converter, with COE and NPC **US\$0.411/kWh** and **US\$143,616** respectively.
  - iii. The diesel generator-battery-power converter is the third most economic hybrid system, with NPC of **US\$646,967** and COE of **US\$1.85/kWh**
  - iv. The fourth most economic hybrid system is the pv-diesel-power converter with NPC of **US\$1.88M** and COE of **US\$5.37/kWh**
17. The final most economic hybrid system is the diesel generator with NPC of **US\$2.76M** and COE of **US\$7.92/kWh**.
18. In this research work, the PV system is the only renewable power system considered. Therefore, it is recommended that more renewable energy sources can as well be incorporated so as to increase the power gotten from renewable energy sources.

## REFERENCES

- Ali Kadhem, A., Abdul Wahab, N. I., Aris, I., Jasni, J., & Abdalla, A. N. (2017). Reliability Assessment of Power Generation Systems Using Intelligent Search Based on Disparity Theory. *Energies*, 10(3).  
<https://doi.org/10.3390/en10030343>
- Craig, A., Li, X., Sesker, P., Mcinerny, A., DeAgostino, T., & Depcik, C. (2016, April). *Small-Scale Smart Electrical Grid Design, Construction, and Analysis*. <https://doi.org/10.1115/IMECE2016-65219>
- Dong, Z. Y., Borghetti, A., Yamashita, K., Gaikwad, A., Pourbeik, P., & Milanović, J. (2012, April). *CIGRE WG C4.605 Recommendations on Measurement Based and Component Based Load Modelling Practice*.
- Han, S. (2020). Three-Phase-Measurement-Based Load Modeling Technique Using Unbalanced Fault Data. *IEEE Access*, 8, 83655–83662. <https://doi.org/10.1109/ACCESS.2020.2992369>
- Iqbal, J., & Khan, Z. H. (2017). The potential role of renewable energy sources in robot's power system: A case study of Pakistan. *Renewable and Sustainable Energy Reviews*, 75, 106–122.  
<https://doi.org/https://doi.org/10.1016/j.rser.2016.10.055>
- Kontis, E. O., Papagiannis, G. K., Syed, M. H., Guillo-Sansano, E., Burt, G. M., Papadopoulos, T. A., & Chrysochos, A. I. (2017). Development of measurement-based load models for the dynamic simulation of distribution grids. *2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, 1–6.  
<https://doi.org/10.1109/ISGTEurope.2017.8260251>
- Lasseter, R., Akhil, A., Marnay, C., Stephens, J., Dagle, J., Guttromsø, R., Meliopoulos, A. S., Yinger, R., & Eto, J. (2003). *Integration of distributed energy resources. The CERTS Microgrid Concept*.
- Rocabert, J., Luna, A., Blaabjerg, F., & Rodríguez, P. (2012). Control of Power Converters in AC Microgrids. *IEEE Transactions on Power Electronics*, 27(11), 4734–4749. <https://doi.org/10.1109/TPEL.2012.2199334>
- Saviozzi, M., Silvestro, F., & Massucco, S. (2018). Implementation of Advanced Functionalities for Distribution Management Systems: Load Forecasting and Modeling through Artificial Neural Networks Ensembles. *Electric Power Systems Research*, 167. <https://doi.org/10.1016/j.epsr.2018.10.036>
- Sharafi, A., Vahidnia, A., & Jalili, M. (2019). Measurement-Based Identification of System Load Models for Low-Frequency Dynamics. *2019 9th International Conference on Power and Energy Systems (ICPES)*, 1–6.  
<https://doi.org/10.1109/ICPES47639.2019.9105598>
- Singh, V. P., Kishor, N., & Samuel, P. (2016). Communication time delay estimation for load frequency control in two-area power system. *Ad Hoc Networks*, 41, 69–85.
- Zamani-Gargari, M., Kalavani, F., Abapour, M., & Mohammadi-Ivatloo, B. (2018). Reliability assessment of generating systems containing wind power and air separation unit with cryogenic energy storage. *Journal of Energy Storage*, 16, 116–124. <https://doi.org/https://doi.org/10.1016/j.est.2017.12.013>
- Zubo, R. H. A., Mokryani, G., & Abd-Alhameed, R. (2018). Optimal operation of distribution networks with high penetration of wind and solar power within a joint active and reactive distribution market environment. *Applied Energy*, 220, 713–722.  
<https://doi.org/https://doi.org/10.1016/j.apenergy.2018.02.016>