OPTIMAL CONTROL OF DVR TO ENHANCE THE POWER QUALITY OF PV/WIND/FUEL CELL HYBRID SYSTEM FEEDING A NEW COMMUNITY

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ABSTRACT

This article presents a control of Dynamic Voltage Restorer (DVR) to enhance the power quality (PQ) of a stand-alone PV/wind/fuel cell hybrid system feeding a new community. The optimal size of the proposed system is obtained using the Homer simulation tool. The controller proposed in this article is a PI controller based on cuckoo search optimization technique. Cuckoo search is applied to PI controller to solve the problem of optimization parameters. Two test cases are investigated including (three phase fault and sag voltage) to prove the quality of DVR based PI-CS controller. The disturbances applied to the proposed system are avoided using Dynamic voltage restorer (DVR) while the PV/Wind/Fuel cell hybrid system continues its normal operation and the power quality is enhanced. The simulation model of the hybrid system with DVR using PI-CS is designed in MATLAB/Simulink. Results show the ability of DVR with Controller to overcome and compensate voltage sags as well as faults.

INTRODUCTION

North African countries have begun to adopt new energy policies increasingly dependent on renewable energies such as solar, wind power, fuel cells… etc., especially as some of these countries, such as Egypt, have huge potential for using solar and wind to produce energy. A large percentage of electricity in Egypt is still produced by fossil fuels, which is a great burden on the environment, but also on the state budget, especially that the reserves available in the country of oil and gas are limited [1]. The fusion of hybrid system and their advantages in generating energies, particularly in remote areas, are inevitable. The hybrid energy system is an important and accurate research point for many researchers. Hybrid renewable-energy systems have become popular to measure up electricity demands [2]. The control process of these systems is considered as an important issue [3]. Power quality problems in electrical power systems are one of the most important issues to focus on to reach reliable energy. The problems of power quality may be represented in Service mal-operation, a different voltage value, currents and transient voltages and harmonics of current and voltage waveforms. End users and utilities are very interested in quality problems in all fields of electric power [4]. The greatest challenge is to maintain the quality of electric power within acceptable limits. The negative effects of poor electrical power quality are explained in [5]. Reducing distortions in voltage and current waveforms is an important issue, a Dynamic Voltage Restorer (DVR) may be used for this purpose as in [6]. In this paper, a PI controller based cuckoo search of the DVR is developed to ameliorate the power quality of off-grid hybrid system feeding a new community in Egypt -Case Study New El-Farafra Oasis. The hybrid system as in Fig.1 consists of PV system, wind turbine based permanent magnet synchronous generator and Fuel cell. Each generation source connected to DC-DC boost converter. All generation sources are tied through DC link. Community AC loads are fed through an inverter. The disturbance is applied to the system proposed so that the DVR is inserted into the system to mitigate the voltage sag, faulty voltage and improve power quality of the system. Any distortion in Supply voltage Vs at feeder F1 may be compensated at the load voltage at feeder F2 by injecting appropriate voltage from voltage source inverter (VSI) through an injection transformer. PI controller at each test case is produced which tuned by CS. Results show the ability of PI-CS control for mitigating voltage sag and short circuit, moreover enhance power quality of the system.

SYSTEM MODELING

The PV system data shown in appendix A. on the other hand, the wind turbine data shown in appendix B. In this work, Solid Oxide Fuel Cell (SOFC) is utilized, the fuel cell data shown in appendix B. The compensated faulty voltage depth is the primary step in calculating DVR rating, where DVR data, battery and transmission line data are shown in appendix C.

Optimal Sizing using Homer Software [7]

In this paper, HOMER software used to obtain the optimal size of PV/Wind/Fuel cell hybrid system to feed the AC loads of a new community. By running simulation, HOMER selected the feasible and optimal cases and sorts it with least present cost. Simulation results show that the optimal system is 30.687 MW PV-array, 13.5 MW wind turbines, 46 MW fuel cell, generic 1 kWh lead-acid battery (117,089 strings) and system converter (32.911 MW). All generation sources are tied through a DC link 780 V DC and then converted to AC through an inverter for feeding AC community loads.

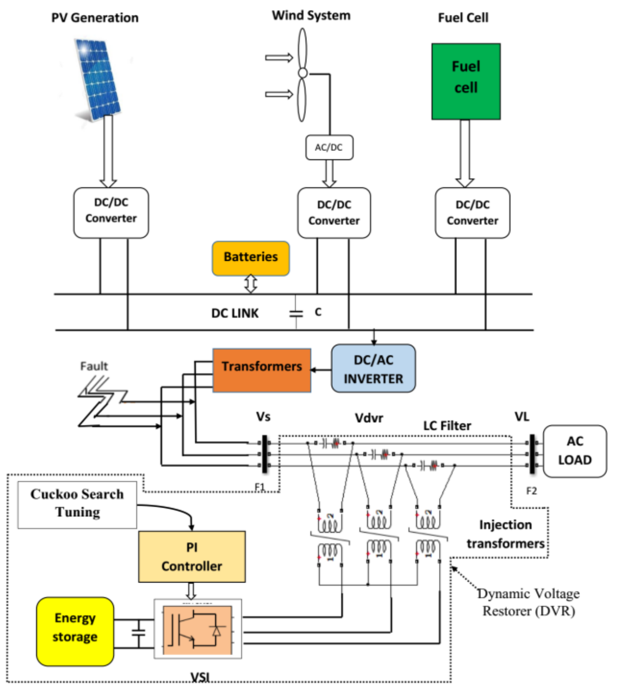


Fig.1 Block diagram of hybrid system with DVR.

CONTROLLER DESIGN

PI Controller

The error between actual values and reference values of DQ voltage is used as an input to the PI controller of DVR. The output is converted to ABC coordinates, then it is directed to the PWM to give appropriate pulses for the IGBT of VSI. Fig. 2 shows the control circuit of PI controller, which is simulated in MATLAB Simulink.

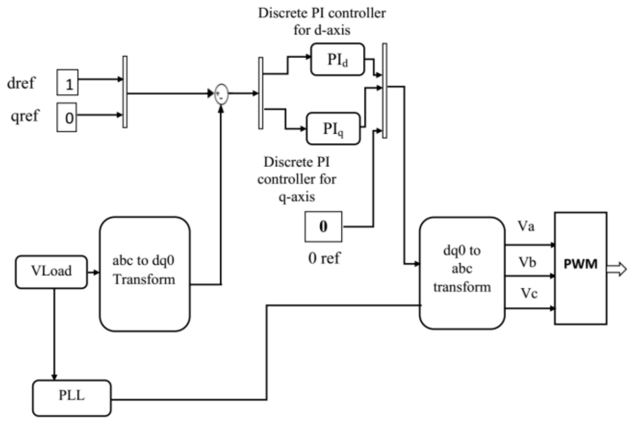


Fig. 2 PI control circuit

The load voltage (V Load) is measured, then transformed to dq0 coordinates, the error between the dq voltages and a reference voltage of DQ coordinates represent the input of PI controller, the d reference is 1 p.u (rated voltage) and q reference is 0. Two PI controllers are used for d and q error signals PI_d, PI_q respectively. The output of the PI controller is transformed to ABC then forwarded to PWM for triggering IGBT of VSI.

Cuckoo Search (CS) for tuning PI controller

Cuckoo birds start in looking for the best nest, but this step has an important role in the cuckoo's reproduction method. The walks and directions are chosen and modeled on certain mathematical functions, le'vy flight is one of the most common models. Le'vy flight is an irregular stroll in which the step lengths have a probability distribution and these steps are defined in terms of the step lengths. In CS, the step length is extracted from le'vy distribution according to power law [8, 9], i.e.

$$\text{Le'vy} \sim u = t^{-\lambda} \qquad \text{where } (1 < \lambda \leq 3), \tag{1}$$

Flow Chart of CS algorithm is shown in fig.3.

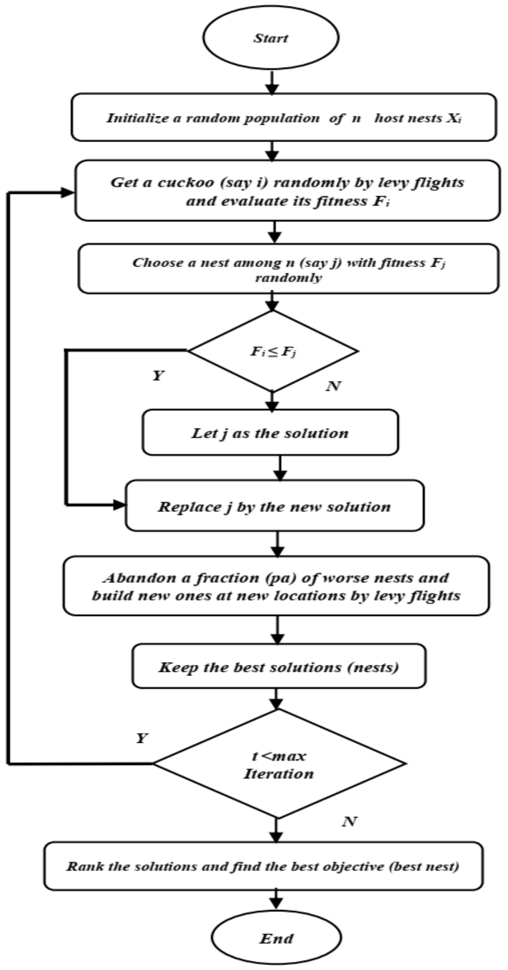


Fig. 3 Flow Chart of CS algorithm

For a PI controller tuned by CS, indices are summarized to depict the system performance such as ISE, it is defined as follows:

$$ISE = \int_0^\infty e^2(t)dt \tag{2}$$

Equation (2) represents performance index for tuning PI controller using CS. it will be used as the objective function with minimum performance index.

The PI optimized values are obtained in each test case. The parameters of the PI controllers are optimized with CS algorism under different cases namely, three phase fault and Sag voltage. The CS optimized PI controller parameters for the two cases are given in Table 1.

Table: 1 Optimized parameters of PI controllers obtained by Cuckoo Search (CS) tuning algorithm for different cases

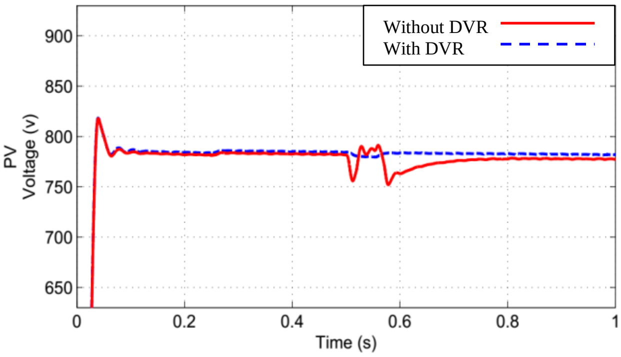
Cases	D-axis		Q-axis	
	Kpd	Kid	Kpq	Kiq
3-phase fault	8.541	199.002	77.320	190.601
sag voltage	78.60	194.80	84.01	123.81

RESULTS AND DISCUSSIONS

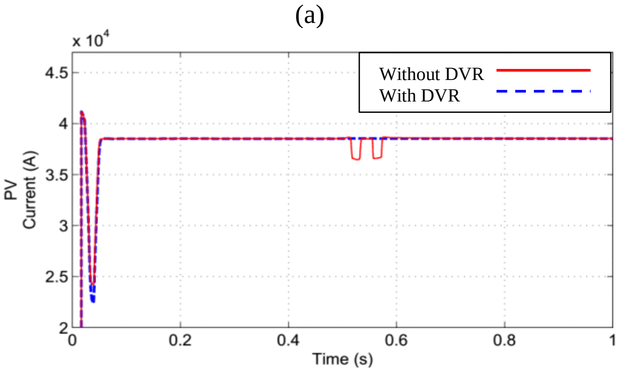
The PV/Wind/fuel cell hybrid system feeding AC loads of a newly proposed community in Egypt, shown in Fig. 1 is used to test the validity of the proposed PI controller optimized by CS of DVR for enhancement this integration considering sag and three phase short circuit.

Test case 1: fault at the F1 with a clearing time of 0.05 s

Fault at the F1 with 0.05 s fault clearing time between 0.5 and 0.55 s is applied in this case. Without integrating DVR, the system is mightily affected by this short circuit and critical instability in the output waveforms. With DVR and the same fault is applied to the system, there is a noticeable improvement in the output waveforms. The output waveforms are distorted without using DVR. Figs (4-6) show the effect of a short circuit on RMS voltage, current and power waveforms of PV generator, fuel cell and wind system respectively.



(a)



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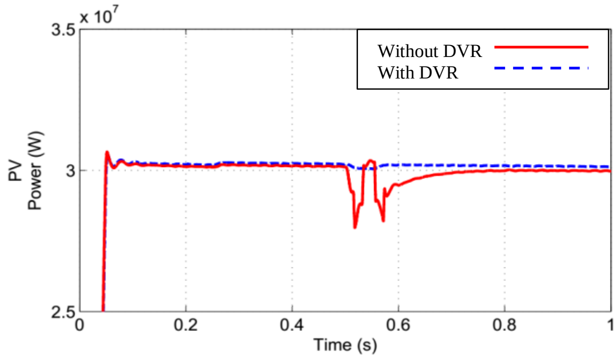
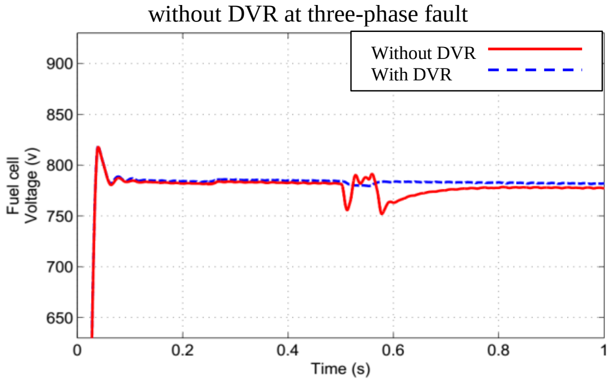


(c)

Fig. 4 PV output (a) voltage (b) current (c) power with and without DVR at three-phase fault



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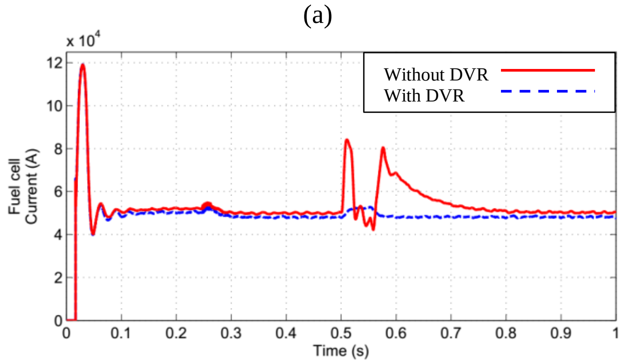

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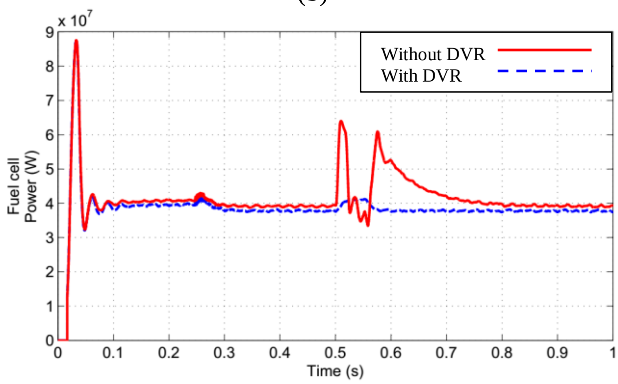
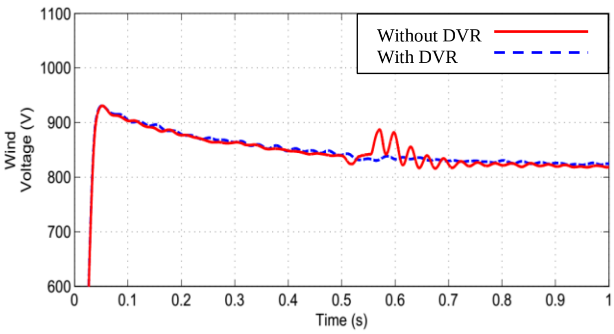


(c)

Fig. 5 Fuel cell output (a) voltage (b) current (c) power with and without DVR at three-phase fault.



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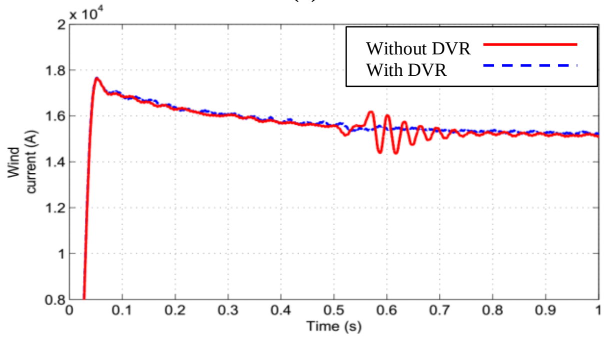

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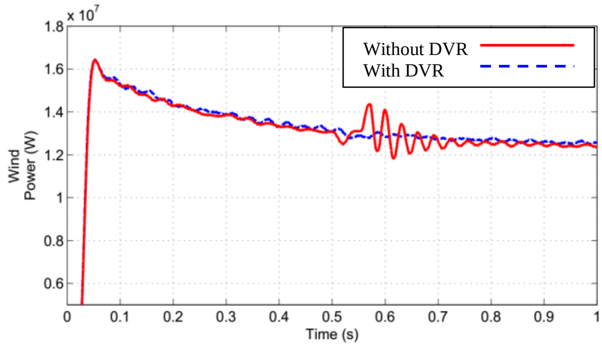


(c)

Fig. 6 Wind system output (a) voltage (b) current (c) power with and without DVR at 3 phase fault

The generator rotor speed of the wind turbine is plotted in this case with and without DVR in Fig. 7. When a fault occurs, the electrical torque (Te) pulsates includes more oscillations which have a great low-frequency value and, as a result, a total breakdown of the system due to severe vibration on the mechanical part of the system. On the other hand, the generator speed is accelerated and increased to higher values in the absence of DVR.

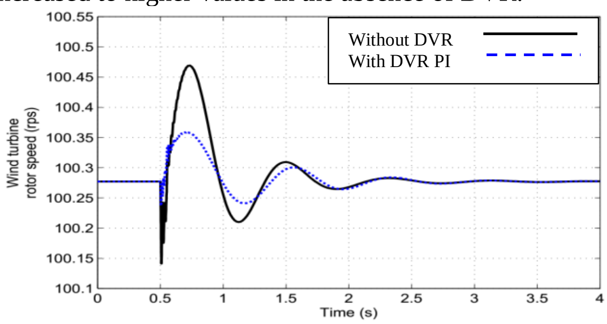
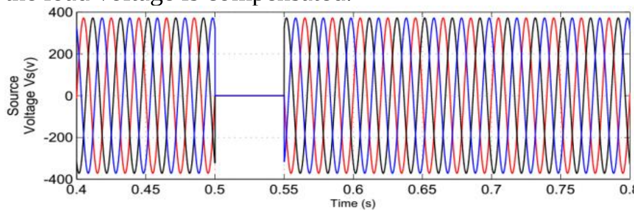
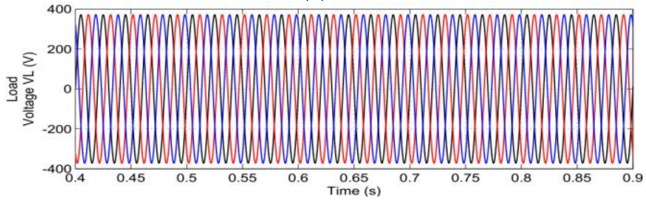


Fig. 7 Rotor wind turbine speed with and without DVR

The supply, load, and injected voltage waveforms when a three-phase short circuit fault occurs are shown in Fig. 8. The PI controller parameters tuning in this case, with the aid of CS. With the proper tuning of controller parameters, the load voltage is compensated.



(a)



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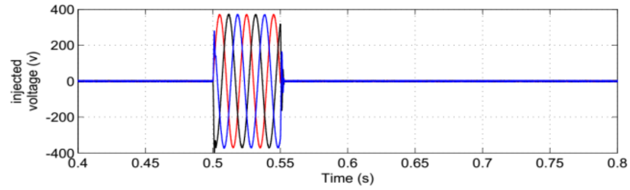

(c)

Fig.8 (a) Source, (b) Load and (c) injected voltages at 3 phase short circuit with the DVR based PI-CS controller

Case 2: voltage sag between 0.5 and 0.7 sec

The simulation result, shown in Fig. 9, clearly shows the voltage sag from 0.5 to 0.7. When the DVR injects voltage from 0.5 to 0.7 Sec, the load voltage is compensated and exactly equal to that of the source voltage. With PI-CS controller, the maximum overshoot decreased and succeeded a rapid response.

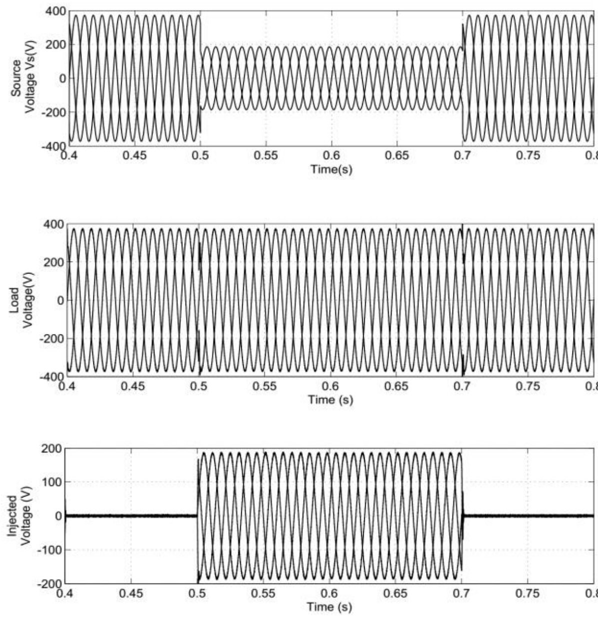

Fig. 9 Source, Load and injected voltages at sag voltage

CONCLUSION

The application of a DVR based PI controller with optimal tuning using Cuckoo Search optimization connected to hybrid PV/Wind/fuel cell feeding a new community in Egypt is investigated. PI controller-based CS algorithm of the DVR has the ability to compensate the voltage sag and faulty line voltage, while Hybrid PV/Wind/Fuel cell continues its operation. Results show the ability of DVR for compensating the disturbance occur in the system, with improvement in voltage, current and power waveforms of the generation sources. The implementation of the Hybrid system with DVR makes an advantage that can ameliorate the power quality of off-grid hybrid power system

REFERENCES

[1] M.O.A El-Raouf, M.I, Mosaad, M.A. Al-Ahmar, and F.M. El Bendary, 2015 'MPPT of hybrid solar wind-grid power generation system', Int. J. Industrial Electronics and Drives, Vol. 2, No. 4, pp.234–241.

[2] Mojtaba Qolipour, Ali Mostafaeipour, Omid Mohseni Tousi, 2017 "Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: A case study" Renewable and sustainable energy reviews Vol. 78, pp. 113-123.

[3] Mohamed I. Mossad, Nagy I. Elkalashy and Mohamed G. Ashmawy, 2018 "Integrating Adaptive Control of Renewable Distributed Switched Reluctance Generation and Feeder Protection Coordination" Electric Power System Research journal, Elsevier, Vol. 154, pp. 452–462.

[4] Dugan RC, Mc Granaghan MF, Santoso S, Beaty HW, 2003 "Electrical power systems quality". 2nd edition New York, USA: Mc Graw-Hill Professional Engineering Series.

[5] Wang X, Blaabjerg F, Wu W, 2014 "Modelling, and analysis of harmonic stability in an ac power-electronics-based power system". IEEE Trans Power Electron; 29(12):6421–32.

[6] A Prajyusha, N Srinivas Rao, B. Naresh, 2018" development of ultra-capacitor-based DVR for power quality improvement" International Journal of Innovative Technology and Research Vol.6 No.1.

[7] M. Osama abed el-Raouf, Mohamed I. Mosaad, Mahmoud A. Al-Ahmar and Fahmy M El Bendary, 2018 "Techno-Economic Analysis of Hybrid Renewable Energy Power Network for New Community in Egypt, Case Study New El-Farafra Oasis" International Journal of Engineering Research and Advanced Technology (IJERAT) Vol. 4, Issue 5.

[8] R. Rajabioun, 2011 "Cuckoo Optimization Algorithm," Applied Soft Computing. Vol. 11, pp. 5508-5518.

[9] X.-S. Yang, S. Deb, 2009 "Cuckoo search via Le'vy flights", in: Proc. Of World Congress on Nature & Biologically Inspired Computing (NaBIC), December 2009, India. IEEE Publications, USA, pp. 210-214.

Appendix

A. Photovoltaic data.

Table: 1 Specifications of PV panel.

Description	Specifications	
PV Panel type	Solar MSX60 60 W	
Open circuit voltage	V_{OC}	21.0 V
Short circuit current	I_{sc}	3.74 A
The voltage at max power	V_m	17.1 V
Current at max power	I_m	3.5 A
The Power used by Ppv system	Ppv	31 MW

B. Wind and Fuel cell data

Table 2: Wind turbine data

Parameters	Unit	Specifications
Rated power	KW	1500
Cut in wind speed	m/s	3
Rated wind speed	m/s	10.3
Cut out wind speed	m/s	22
Number of turbines used		9
Rotor		
Rotor Diameter	M	82
Rotor Swept Area	m^2	5325
Generator		
Generator type	Permanent Magnet Synchronous Generator (PMSG)	
Rated power	KW	1580
Rated voltage	V	720
Rated Rotor Speed	RPM	17.3
Rated frequency	Hz	50

Table: 3 Fuel cell data

Parameters	Specifications
Fuel cell type	Solid oxide (SOFC)
Common Electrolyte	Yttrium stabilized Zirconia
Operating Temperature	700-1000°C /1202-1832°F
Typical Stack Size	2 MW
Efficiency	60%
The number of fuel cell used	23

C. Battery and transmission line model data

Table: 4 Battery specifications.

Description	Specifications
Battery model	Lead-acid battery
Maximum capacity	83.4 Ah
Nominal voltage	12 V
Round tip efficiency	80 %
Nominal energy capacity of battery	1 kWh

Table: 5 Transmission line data.

Description Length (km)	Resistance (Ω/km)	Inductance (H/km)	Capacitance (F/km)
4.5 km	0.07	$3.01*10^{-4}$	$1*10^{-12}$

Table 6: DVR data

Description	Symbol	Specifications
DVR DC voltage	Vdc	700 v
DVR capacitor DC link	C DC	5000 µF