Evaluation of an autonomous microgrid for rural electrification in Zahedan, Sistan Va Baluchestan

Homa Rashidizadeh Kermani Mostafa Vahedipour Dahraie Hamid Reza Najafi
Department of Electrical Engineering, Birjand University, Birjand, Iran

rashidi_homa@birjand.ac.ir vahedipour_m@birjand.ac.ir h.r.najafi@birjand.ac.ir

***Abstract*—Electrification of rural places is always a big challenge. Such regions are usually far from utility grid, so an autonomous microgrid is a proper option to increase the availability of electricity in those places. Since Sistan Va Baluchestan has windy and sunny weather, it is proposed to use an autonomous microgrid including photovoltaic (PV), wind turbine (WT) and diesel generator based on synchronous generator (SG) its rural places. In the proposed model, SG keeps balance between generation and demand as a backup unit. When PV and WT are able to supply the rural load, SG goes to stand by mode and While PV and WT are not able to supply the customers, SG generates. In this scheme, to keep frequency within its nominal value, a specific strategy is used. In this strategy, some Non-Critical Loads (N-CLs) which are able to adjust their consumption based on the frequency variation are used. The dominant characteristic of this model is to control frequency without any storage. Different scenarios are defined to assess the successful performance of the system.**

Keywords-microgrid; synchronous generator; wind turbine; photovoltaic; rural places; Sistan Va Baluchestan.

I. INTRODUCTION

Microgrid is a good concept to integrate renewable energy resources in rural places in which people are limited access of main grid. In such places, grid connection is impractical or too expensive [1]. Compared with a traditional interconnected utility grid, a microgrid is geographically closer to local loads. So, this feature enables a microgrid to reduce electrical transmission costs by reducing both the transmission construction and loss cost. Also, microgrid is a flexible utilization of distributed generations increasing the reliability of critical loads, provide better reactive power management, and optimize the operation at the distribution level [2].

From the customer point of view, microgrids provide both thermal and electricity needs and in addition enhance local reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips and potentially lower costs of energy supply.

In the last decade, serious concerns were raised about distributed generation units, such as WT, PV, gas microturbines, fuel cells and gas/steam powered combined heat and power (CHP) stations. In [3] an integrated system consisting of a WTs and a SG is simulated and different conditions under the disturbances are assessed.

When a microgrid operates at autonomous mode, voltage and frequency should be supported by a microgrid itself, usually through SGs. For a microgrid without SGs, the system voltage and frequency would be difficult to maintain without the support of the ac grid. One solution is to use a voltage source converter interfaced energy sources to provide voltage and frequency control [4-8]. In fact battery is employed to restore system voltage and frequency quickly (several cycles). In an autonomous microgrid, the control objective is to maintain the voltage amplitude and frequency within the acceptable levels while achieving reasonable power sharing [9-10].

The autonomous microgrid is an appropriate option for rural regions, especially when such places have strong wind or solar energy potential. The studies show that Sistan Va Baluchestan has a good potential for installing PVs and WTs [11-12]. So the autonomous microgrid can be proposed in order to electrification of remote regions in this province. Since rural areas are far from the main grid in this region, autonomous microgrid scheme can reduce the electrification costs.

In this paper an autonomous microgrid including PV, WT and SG is proposed to supply demand of a rural place in Sistan Va Baluchestan. In the proposed model, N-CL are applied to control frequency.

The remainder of this paper is organized as follows. The system modeling is discussed in Section II. The simulation and results are presented in Section III and the conclusion is drawn in Section IV.

II. SYSTEM MODELLING

The under study microgrid is illustrated in “Fig. 1”. The system consists of four feeders, loads, control system and three energy resources including a diesel generator, wind turbine and a photovoltaic system. The diesel generator consists of a SG driven by a diesel engine. The SG is equipped with a turbine-governor and automatic voltage regulator systems, connects to Bus1. Wind turbine includes an asynchronous generator connects to Bus2 and a photovoltaic system connects to Bus 3. Also, load and N-CL connect to Bus4. The microgrid is assumed to be operational and can meet corresponding loads in autonomous mode.

978-1-4673-6612-0/15/$31.00 ©2015 IEEE

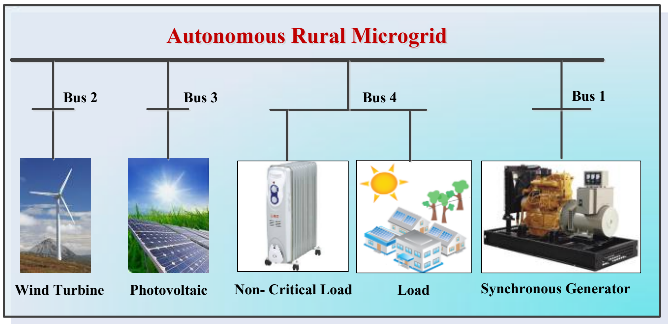

Figure 1. The autonomous microgrid under study

A. Model of Diesel Generator

Diesel generator consists of a prime mover such as a diesel engine, and a three-phase synchronous generator with excitation and governor control systems. The generator and the diesel engine are mechanically coupled.

The turbine-governor system of SG controls the power-frequency characteristics. In fact the purpose of this mechanism is to sense the machine speed and adjust the input valve in order to change the mechanical power output. Ideally, this adjustment will compensate for the load changes and restore the frequency back to its nominal value.

A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level. It keeps relatively constant output voltage while voltage and load current changes over time [13].

The synchronous generator used in this study is 300kVA and 480 V.

B. Model of Wind Turbine

Wind turbine is an environmentally-friendly power generation source which captures the kinetic energy of wind and transfers it to the electrical part through a gearbox [14-15].

The power of the wind is proportional to wind speed to the power of three ($V^3{}_{wind}$), air density (ρ) -typically 1.225 kg/m^3 - and cross sectional area of rotor (A). The following equation describes it:

$$P_{wind} = \frac{1}{2}\rho V^3_{wind} A \qquad (1)$$

In this study the rated power of wind turbine is 400 kW. Below a specific speed called cut-in wind speed, of about 4.5 m/s, the wind turbine remains shut down as the power in the wind is too low for useful energy production. Then, once operating, the power output increases following a broadly cubic relationship with wind speed until rated wind speed (10 m/s) is reached. Above rated wind speed the aerodynamic rotor is arranged to limit the mechanical power extracted from the wind and so reduce the mechanical loads on the drive train. Then, in very high wind speeds (over 16 m/s), the turbine is shut down. The power equation can be written in the following form:

$$P = \begin{cases} 0 & V < V_{cut-in} \\ \frac{1}{2}\rho V^3_{Wind} A C_P & V_{cut-in} < V < V_{rated} \\ P_{rated} & V_{rated} < V < V_{cut-out} \\ 0 & V > V_{cut-out} \end{cases} \qquad (2)$$

C_P reveals the capability of turbine for obtaining energy from wind ($C_P \leq 0.593$ (Betz limit)). Thus, the maximum power that can be realized from a wind system is 59.3% of the total wind power [16]. The steady-state output power of the under study wind turbine is illustrated in “Fig. 2”.

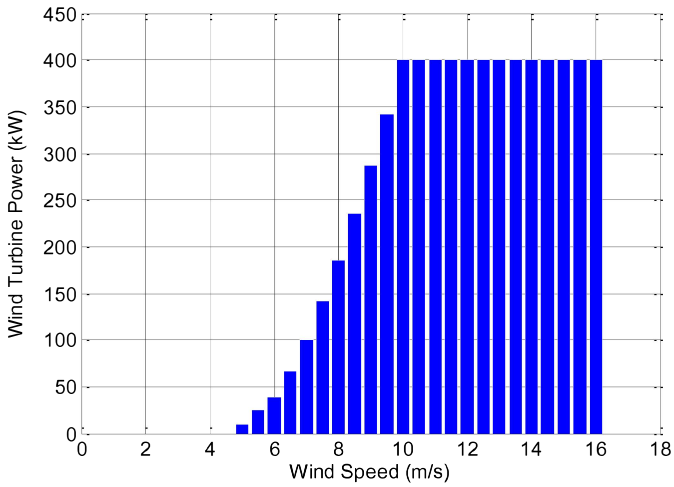

Figure 2. The under study wind turbine power curve

C. Model of Photovoltaic

Photovoltaic system is an average model of a 200 kW array connected to microgrid via two DC-DC boost converters and a single three-phase VSC. The MPPT controller based on the “Perturb and Observe” technique is implemented by means of a MATLAB Function block. The detailed model contains:

- PV array delivering a maximum of 200 kW at $1000\,W/m^2$ sun irradiance.
- A 5 kHz boost converter increasing the voltage of PV natural voltage (272 V DC at maximum power) to 500 V DC. Switching duty cycle is optimized by the MPPT controller.
- A 1980 Hz (33*60) 3-level 3-phase VSC converts the 500 V DC to 260 V AC and keeps unity power factor.
- 10 kvar capacitor bank filtering harmonics produced by VSC.

D. Load and Dump Load

The consumption loads in rural places can be divided into two types. There are “critical loads” (always must be supplied by the microgrid) and “non-critical loads” (such as cooling or heating loads).

A frequency controller is required to maintain microgrid frequency within its nominal value by changing its consumption based on frequency variation. N-CL can change from 0-100 kW based on frequency variations. The performance of N-CL is in this way that while encountering a frequency increment, N-CL absorbs power and try to reduce the frequency to reach its rated value. As the frequency comes down, the N-CL reduces its consumption.

The dominant concept of this rural microgrid is to control frequency without any storage. To reach this objective, two controllers are embedded: The local controller and the N-CL. The local controller is the conventional controller being in resources and the N-CL is a general controller operating in high frequency amounts.

E. Case Study

The collected solar radiation and wind speed data in the site of Zahedan, located in Sistan Va Baluchestan, Iran, was used in this study. Sistan Va Baluchestan has a hot desert climate and over the course of a year, the temperature typically varies from $0^{o}C$ to $37^{o}C$ and is rarely below $-6^{o}C$ or above $40^{o}C$. "Fig. 3" shows the daily high and low temperature of Zahedan, from 1999 to 2012 [17].

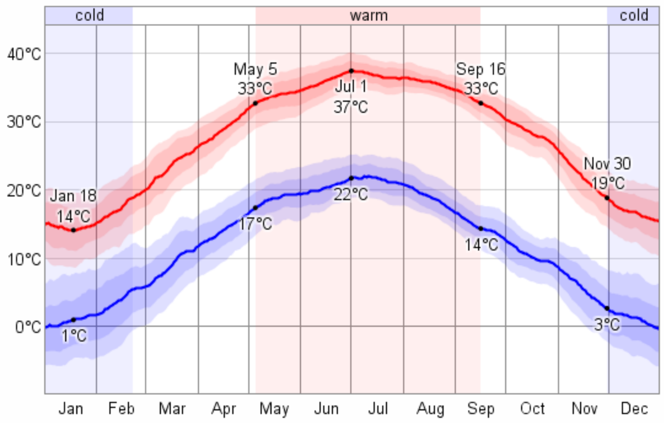

Figure 3. The average daily high (red) and low (blue) temperature of Zahedan.

The length of the day varies significantly over course of the year. "Fig. 4" shows the daily hours of daylight and twilight in Zahedan [13]. As it is obvious, the sun shines in most of hours during a year.

A sample day in March is considered in this study. The average sun radiation in this day is illustrated in "Fig. 5". It shows that the sun radiation reaches a high level at about 14:00 pm in which the solar radiation is $700W/m^{2}$. So based on obtained data in Zahedan, photovoltaic can be a proper option in order to generate electricity in this region.

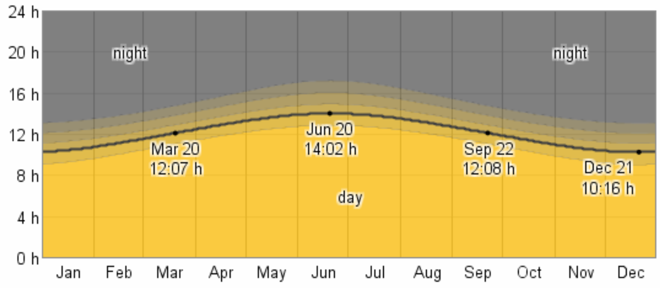

Figure 4. Daily hours of daylight (yellow) and twilight (gray)

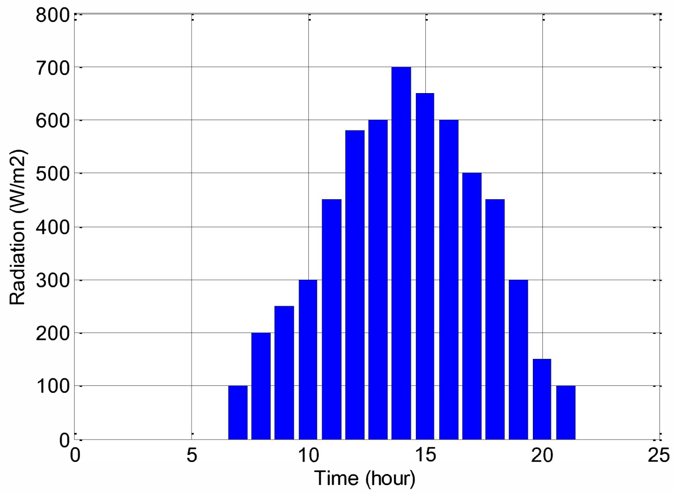

Figure 5. Daily sun radiation curve

The value of daily wind speed during a year in Zahedan is depicted in "Fig. 6". It shows that over the course of a year, typical wind speeds vary from 0 to 10 m/s, rarely exceeding 14 m/s and it is clear that this region has strong wind energy potential. The wind speed data for March 20 is given in "Fig 7". So based on the propper wind behavior in Zahedan, wind generation can be a good choice in this region.

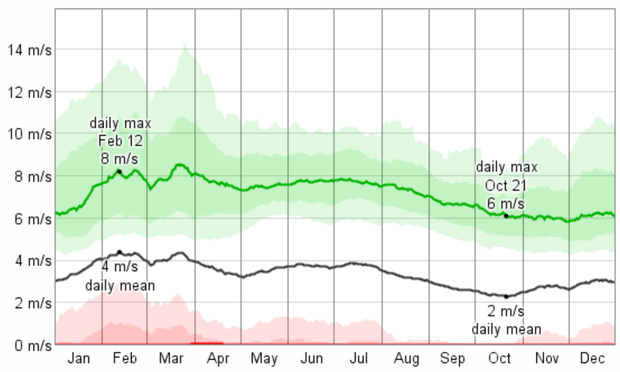

Figure 6. The average daily minimum (red), maximum (green), and average(black) wind speed during a year in Zahedan

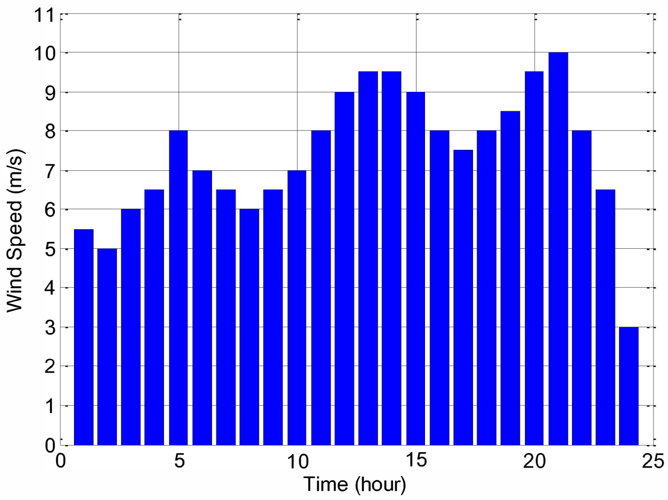

Figure 7. Daily wind speed curve

The load curve is a good visual representation of electricity use and its variation over time. In this study the daily load of a rural place in Zahedan in March 20 is considered. "Fig 8" shows minimum and maximum demand values are 170 and 500 kW, respectively.
Based on the aforementioned conditions in Zahedan, a rural microgrid including wind turbine and PV is attractive.

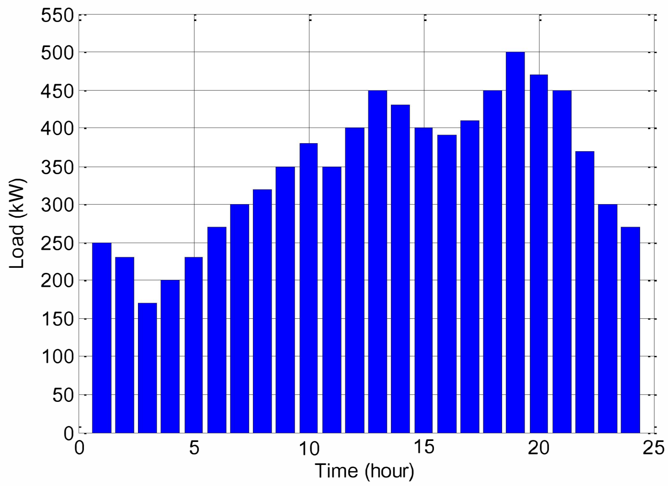

Figure 8. Daily rural load in March 20

III. RESULT OF SIMULATION

Based on the obtained data such as solar radiation, temperature, wind speed and load curve in March 20 in Zahedan, a rural microgrid is simulated. "Fig. 9" shows generation and demand in this case. It is obvious that SG supports PV and wind turbine. While demand is more than generation of PV and wind turbine, SG generates power in order to supply the surplus load. Whenever the PV and wind turbine can meet load, the SG doesn't generate power and goes to stand by mode. So this is a green scheme which is environmentally friendly. For example at 5:00 AM, the load is 230 kW, the generation of WT and PV is 185 and 0 kW, respectively. So SG compensates the excess demand. At 8:00 AM, the consumption increased to 350 kW. The produced power of WT and PV is 185 and 83 kW, respectively. So SG increases its generation to supply the demand. Between 12:00 to 16:00 PM, the generation of WT and PV increases. So SG generates less power. "Fig 9" illustrates that the consumption of N-CL varies between 20 to 50kW to compensate frequency variation and keep it within its nominal value.

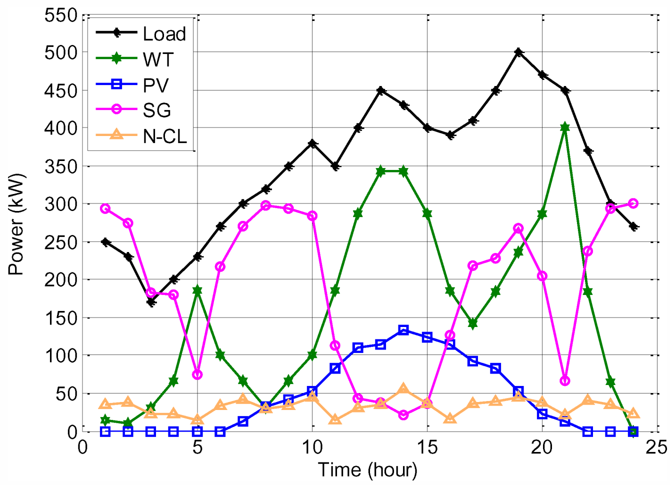

Figure 9. Microgrid generation and demand

In order to assess the performance of this microgrid, some scenarios are considered.

A. Scenario I: Load Variation

In this scenario the solar radiation is $700W/m^2$ and the wind speed is $9m/s$. In this condition, the PV and WT generate 135 and 285 kW, respectively. The load is 400 kW and it increases at t=7s and t=14s to 500 and 600 kW, respectively. The generation of units is depicted in "Fig 10".With respect to the constant wind speed and solar radiation, the SG increases its generation to supply the load. N-CL decreased its consumption to maintain frequency within its nominal value. "Fig 11" shows the frequency and voltage variations.

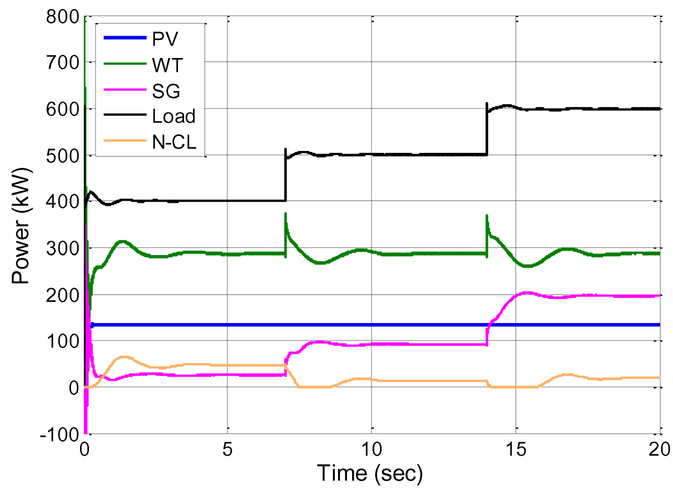

Figure 10. Power of resources and load (scenario I)

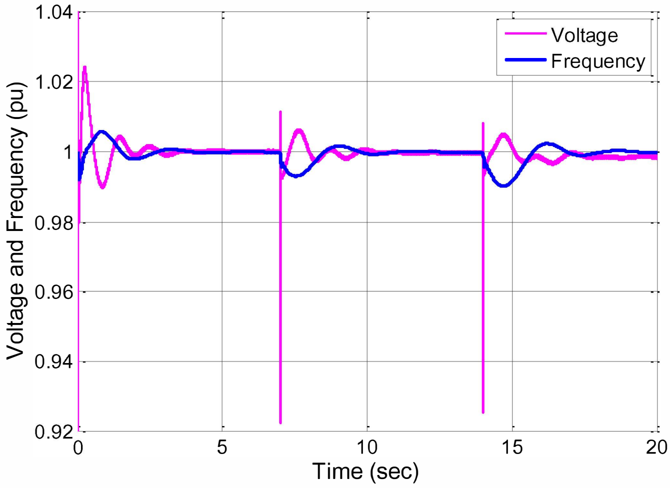

Figure 11. Microgrid frequency and voltage variation (scenario I)

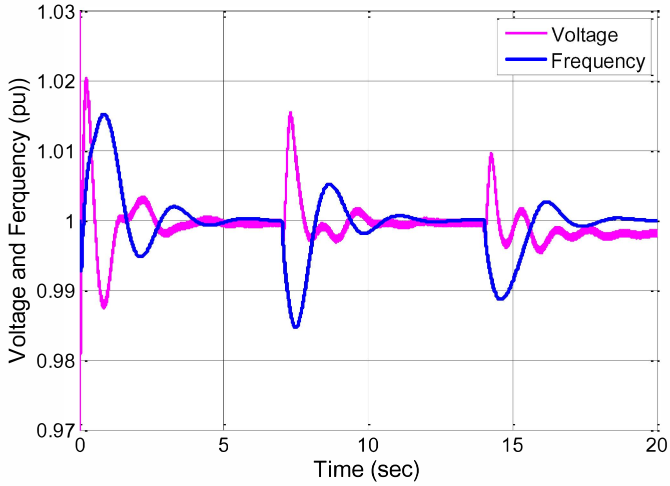

Figure 13. Microgrid frequency and voltage variation (scenario II)

B. Scenario II: Change of Wind Speed

In this scenario the load is 400 kW and the solar radiation is $700W/m^2$. The wind speed is $10m/s$ that changes at t=7s and t=14s to 8 and 6m/s, respectively. "Fig 12" shows the generation of units in this scenario. It is clear that decreasing the wind speed causes the decrement of WT generation, so the generation of SG increases to meet the load. As the proposed scheme is environmentally friendly, whenever the generation of renewable resources decreases, the consumption of N-CL decreases. In addition to this, N-CL plays its role as the frequency controller. The frequency and voltage variations are illustrated in "Fig13".

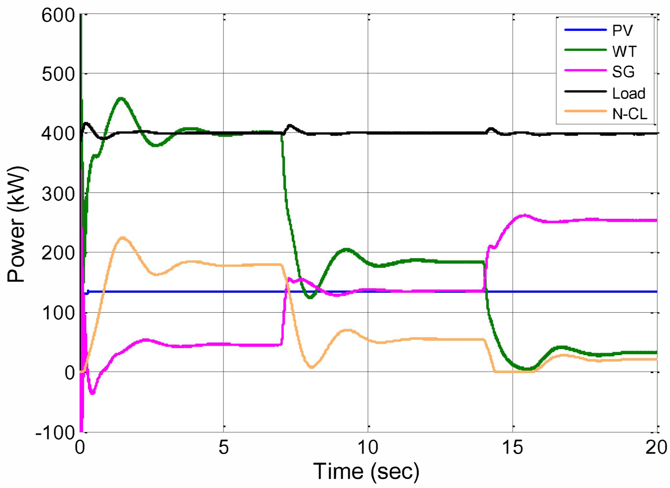

Figure 12. Power of resources and load (scenario II)

C. Scenario III: Change of solar radiation

In this scenario the load is 400 kW and the wind speed is $9m/s$. The solar radiation is $1000W/m^2$ that changes at t=5, t=10s, t=15s to $700W/m^2$, $400W/m^2$ and $100W/m^2$, respectively. "Fig 14" shows the generation of units in this scenario.

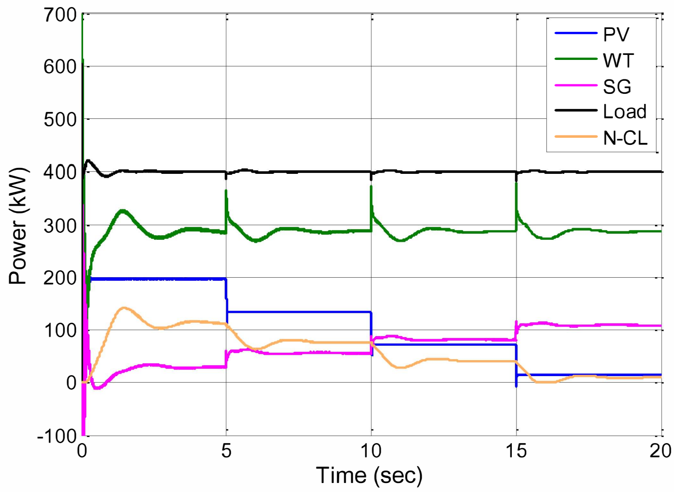

Figure 14. Power of resources and load (scenario III)

As the solar radiation decreases, the PV generation reduces and the SG compensates the surplus load. The N-CL consumption relates to green resource generation. In fact, while the generation of renewable resources decreases, the consumption of N-CL reduces. The frequency and voltage variations in this scenario are illustrated in "Fig15". When the weather conditions changes, the frequency and voltage remain within their permissible limitation.

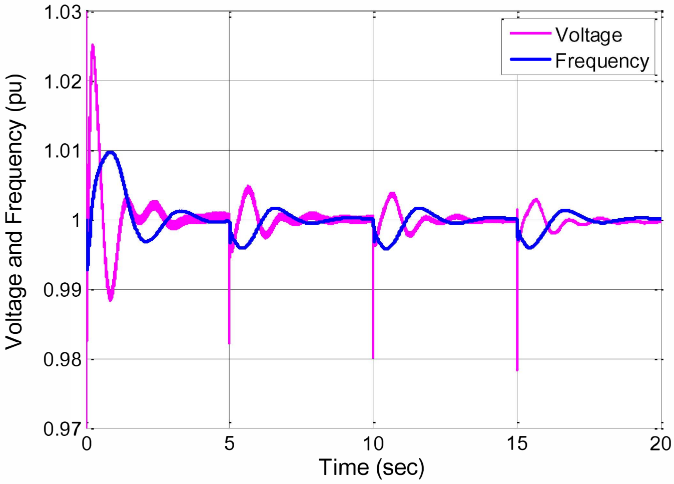

Figure 15. Microgrid frequency and voltage variation (scenario III)

IV. *CONCLUSION*

To enhance the energy development in Sistan Va Baluchestan, especially in its rural areas, in this paper an autonomous microgrid was simulated. With respect to the weather condition in Sistan Va Baluchestan, the proposed model consists of PV, WT and SG. SG supports the generation whenever PV and WT can not meet demand. The results obtained from different scenarios show that such scheme is a proper option to supply the demand of rural regions. Also this is a green scheme and environmentally friendly. Moreover using such schemes in electrification of regions which are far from the main grid is economical.

Reference

[1] Zhaohao Ding; Wei-Jen Lee; Wetz, D.; Chin-Chu Tsai, "Evaluating the use of a MicroGrid as a power solution for Africa's rural areas," Power and Energy Society General Meeting, 2012 IEEE , vol., no., pp.1,5, 22-26 July 2012

[2] Z. Ding, W.-J. Lee, D. Wetz, and c.-c. Tsai, "Evaluating the use of a MicroGrid as a Power Solution for Africa's Rural Areas," in Power & Energy Sociey General Meeting, 2009. PES'12. IEEE, San Deigo, CA, 2012, pp. 1-5.

[3] G. S. Stavrakakis, and G. N. Kariniotakis, "A general simulation algorithm of the accurate assessement of isolated diesel-wind turbine systems interaction, Part I: A generatl multi-machine power system model" IEEE, Transactions on Energy Conversion, Vol. 10, No. 3, September 1995, pp 577 – 583

[4] H. Karimi, H. Nikkhajoei, and R. Iravani, "Control of an electronicallycoupled distributed resource unit subsequent to an islanding event," IEEE Trans. Power Del., vol. 23, no. 1, pp. 493–501, Jan. 2008.

[5] K. T. Tan, X.Y. Peng, P. L. So, Y. C. Chu, and M. Z. Q. hen,"Centralized Control for Parallel Operation of Distributed Generation Inverters in Microgrids" IEEE Transactions on Smart Grid, 2012.

[6] K. De Brabandere, B. Bolsens, J. Van den Keybus, A. Woyte, and J. Driesen, "A voltage and frequency droop control method for parallel inverters," IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1107–1115, Jul. 2007.

[7] J. M. Guerrero, J. Matas, L. G. Vicuña, M. Castilla, and J. Miret, "Decentralized control for parallel operation of distributed generation inverters using resistive output impedance," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 994–1004, Apr. 2007.

[8] J. A. P. Lopes, C. L. Moreira, and A. G.Madureira, "Defining control strategies for microgrids islanded operation," IEEE Trans. Power Syst., vol. 21, no. 2, pp. 916–924, May 2006.

[9] R. Sebastián, R. Pe˜na Alzola "Simulation of an isolated Wind Diesel System with battery energy storage", Electric Power Systems Research 81 (2011) 677–686

[10] T. L. Vandoorn, B. Meersman, L. Degroote, B. Renders, and L. Vandevelde, "A control strategy for islanded microgrids with dc-link voltage control," IEEE Trans. Power Del., vol. 26, no. 2, pp. 703–713, Apr. 2011.

[11] A. Mostafaeipour, M. Jadidi, K. Mohammadi, A. Sedaghat "An analysis of wind energy potential and economic evaluation in Zahedan, Iran" Renewable and Sustainable Energy Reviews, pp: 641–650, 2014.

[12] M A. Yazdanpanah Jahromi, S. Farahat, S M. Barakati, "A Novel Sizing Methodology Based on Match Evaluation Method for Optimal Sizing of Stand-Alone Hybrid Energy Systems Using NSGA-II", The Journal of Mathematics and Computer Science Vol .5 No.2 ,pp:134-145, 2012.

[13] Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies: 'Dynamic models for fossil fueled steam units on power system studies', IEEE Trans. Power Sys., 1991, 6, (2), pp. 753–761.

[14] S. K. Salman and A. Teo, "Windmill modeling consideration and factors infuluencing the stability of a grid-connected wind power-based embedded generator," IEEE Trans. Power Syst., vol. 18, no. 2, pp. 793–802, May 2003.

[15] Hamid Reza Najafi, Mahmoud Ebadian and Mostafa Vahedipour Dahraie, "The Analytical Investigation of the effect of wind farm equipped with SCIG on static voltage stability by a new index" International Journal of Advanced Research in Computer Science and Software Engineering, Volume 3, Issue 5, May 2013.

[16] R.C. Bansal et al.,2002. On some of the design aspects of wind energy conversion systems, Energy conversion and management, 43:2175-2187.

[17] https://weatherspark.Com/averages, Zahedan, Sistan Va Baluchestan, Iran.