International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2017 | Issue 33 | Volume 9 | Number 4 | Pages 60-66

MODELING AND SIMULATION OF A MICROGRID WITH RENEWABLE SOURCES: STEADY STATE OPERATION AND CONTROL

N.R. Rahmanov [1] N.M. Tabatabaei [2] K.M. Dursun [3] Z.A. Mammadov [1] O.Z. Kerimov [1]

1. Azerbaijan Scientific Research Institute of Energetic and Energy Design, Baku, Azerbaijan
nariman@cpee.az, okerimov@yahoo.com
2. Electrical Engineering Department, Seraj Higher Education Institute, Tabriz, Iran, n.m.tabatabaei@gmail.com
3. Electrical Engineering Department, Ostfold University College, Fredrikstad, Norway, kamil.dursun@hiof.no

Abstract- Operation analysis of microgrid with traditional power sources as diesel generators, low power gas turbines as well as renewables such as wind turbines, PV solar power units and some others are considered in this paper. The models of microgrid with different circuit and power sources are also presented as a result of calculations load flow and minimal level of losses for minimum and maximum load are defined.

Keywords: Microgrid, Wind Turbines, PV Solar Units, Load Flow, Power Loss.

I. INTRODUCTION

In recent years, an increasing attraction to microgrids as one of possible ways of power supply for areas are observed which located relatively far from central power grid such as small towns, enterprises, municipality areas and so on. Scaled application of microgrids would increase local consumers power supply reliability, diminish grid dependence from oil and gas fuel and as an important key they reduce big investment for prospected development of power industry. Many microgrids still continue to be used as diesel generators but the most energies are produced by wind and solar units go down. The microgrids increase energy efficiency using storing devices and improve data monitoring and control capabilities to make an application of various small renewable sources of power as part of microsystem.

One of important advantages of microgrids is allocation of power sources right near consumer. Microgrids may be projected and controlled to provide high reliability of power supply and they may use all available local kind of power as: wind, solar, hydro, geothermal, etc. This paper studies a model of microgrid which comprise of wind turbine, PV solar unit, diesel generator and AC/DC bus systems.

II. TYPICAL STRUCTURE AND MICROGRID CIRCUIT DIAGRAM

At present time there is no strict approach to design a microgrid of distributed generation and researchers are forming the structure of designed network starting from presence of local sources of energy (conventional or non-conventional) and type of load. As a part of microgrid there could be the following sources of power: micro hydro turbine, fuel cell, PV solar unit, wind turbine, diesel generator and micro gas turbine. Generally, we can divide microsystem including various microgrids like Figure 1.

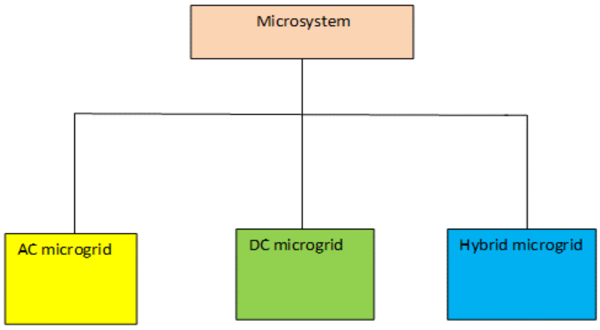

Figure 1. Classification of microsystem including various microgrids

Typical microgrid structure comprises next five important components: micro sources, loads (presented in two categories: important and casual), storing devices, central and local control systems and grid connection unit. Those five components are connected with low voltage network which may operate with outside grid in parallel or island mode. Stable and reliable power supply for network consumers is provided on the base of control and micro sources distribution under supervision of local and central regulating devices.

The principle of coordinated control by means of above mentioned regulators is described in this paper. The microsystem structure in Figure 1 may be realized as electrical network with distributed micro sources feeding AC power bus, DC power bus or combined using AC and DC bus microgrids. The DC microgrid using two-wired system is contrary to four-wired system of AC microgrid. Another advantage of DC microgrid is that it doesn't use transformers so being more reliable and efficient.

In DC microgrid there are no consumers of reactive power and so no reactive power flow. Active power flow is controlled by voltage regulation.

But at AC microgrid the voltage level depends on reactive power flow. There are some practical limitations for wide application of DC Microgrids. The protection systems against different failures in DC microgrids is not fully developed compared with AC microgrids. Typical DC micro system connected with distributed network of outside AC microgrid is presented in Figure 2.

Power sources of AC microgrids include traditional and renewable sources as wind turbines, biogas units and other micro sources generating AC voltage directly connected to AC network buses. The AC microgrids may use the existing power grid distribution network structure and compatible with their operation conditions. At AC microgrids, the AC loads could be directly connected to AC bus terminals without any conversion unit [13]. At some defined conditions, AC microgrids may support grid by producing reactive power and feeding distribution network of the grid. There are a lot of various control devices in the microsystem to control coordination of power production between the sources within the microgrids and meet power demand of local consumers. Operation control of AC microgrids are studied at [14-17]. The typical structure of AC microgrid connected with distribution network of grid is presented in Figure 3.

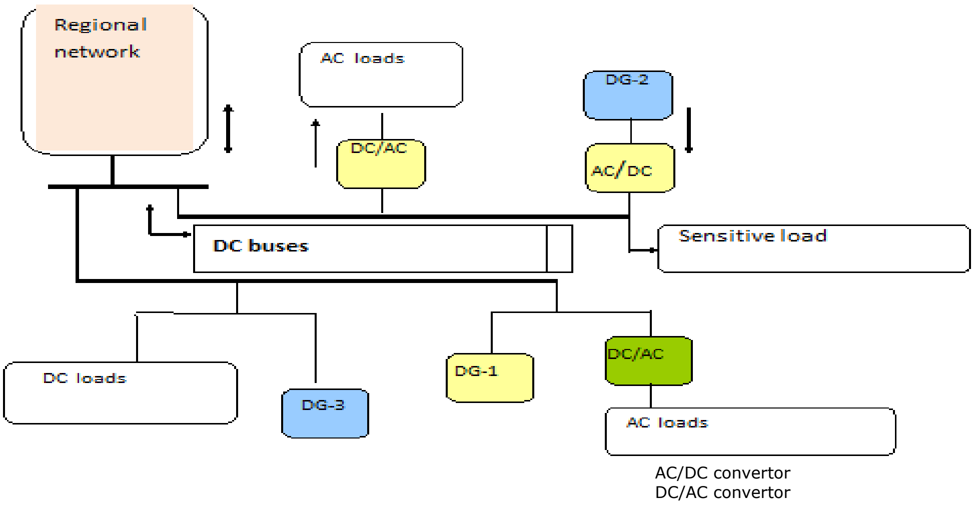

Figure 2. DC microgrid

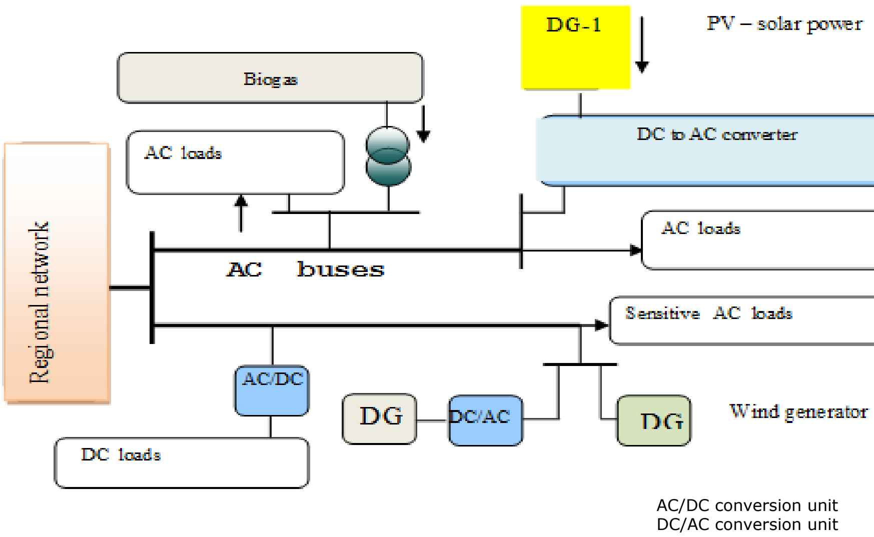

Figure 3. AC microgrid

Hybrid microsystem is a combination of two AC and DC microgrids which are connected with each other by bidirectional converters of AC-DC/DC-AC. The hybrid microsystem has an advantage in relation to DC or AC microgrids including the number of conversion systems from micro sources to microgrid main bus as well as converters between main bus and some loads which would be drastically reduced [22-25]. Modeling and operation control at hybrid microsystem is a considerably complex problem and it is required always to maximize energy production from renewable, and minimization of power exchange between DC and AC microgrid subsystems. It is also required to provide the stable operation of both subsystems considering stochastic character of power production and consumption during parallel and isolated mode of operation of hybrid microsystem and main grid. A hybrid microgrid is shown in Figure 4.

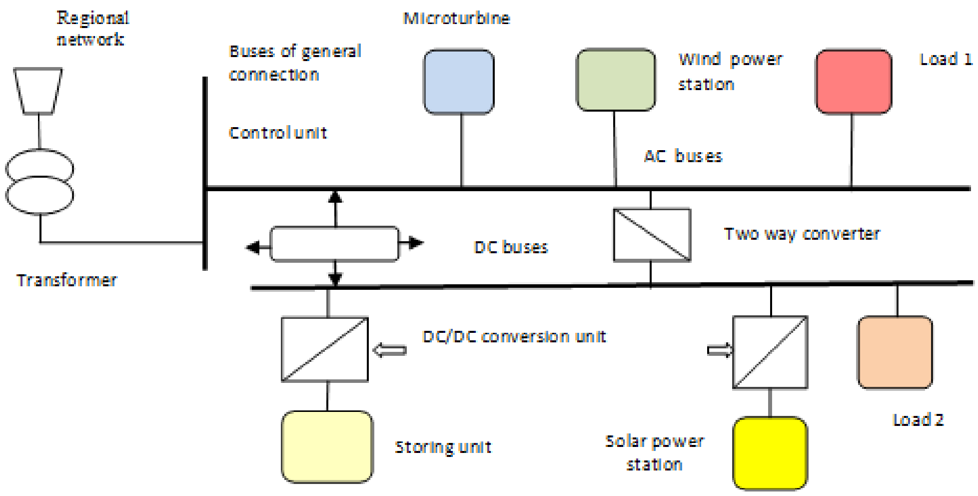

Figure 4. Hybrid microgrid with AC and DC subsystems

III. MODELING OPERATION OF HYBRID MICRO GRID WITH RENEWABLE SOURCES OF POWER

At present, the considerable part of generated renewable power at European countries are wind and solar power. Wind energy is covering about 10.8% of total load demand. It is considered that the main power sources in microgrids are wind and solar units, which are planned to cover maximum of local load.

This paper deals with modeling and operation analysis of hybrid microgrid with wind energy sources and micro turbine connected to AC subsystem of the microgrid and also PV solar units which are connected to DC subsystem.

A. Modeling of Wind Turbine

Taking in consideration that most of wind turbines used in practice apply as Double Fed Induction Generators (DFIG). we study some modeling features of low power (5-1000 kWt) wind turbines and analyze its operation in micro system.

Wind turbines power production is defined by expression [17]:

$$P_m = 0.5\rho A C_p(\lambda,\beta) v_n^3 \qquad (1)$$

where, P is air density (1.225 kg/m^2), A is blades swept area (m^2), v_n is wind speed (m/s) and $C_p(\lambda,\beta)$ is power coefficient, which defined as a function of speed and blades slewing angle. The maximum value of $C_{p,\max}$ is corresponding to λ=8.1 and β=0.

To organize a control system, the mathematical model of DFIG type wind turbine is very important. Applying traditional mathematical form of description for induction machine in rotating d-q coordinates, we have:

- Voltage balance equation

$$\begin{bmatrix} U_{ds} \\ U_{qs} \\ U_{dr} \\ U_{qr} \end{bmatrix} = \begin{bmatrix} -R_s & 0 & 0 & 0 \\ 0 & -R_s & 0 & 0 \\ 0 & 0 & R_s & 0 \\ 0 & 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} + p \begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} + \begin{bmatrix} -\omega_1\lambda_{qs} \\ \omega_1\lambda_{ds} \\ -\omega_2\lambda_{qr} \\ \omega_2\lambda_{dr} \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} = \begin{bmatrix} -L_s & 0 & L_m & 0 \\ 0 & -L_s & 0 & L_m \\ -L_m & 0 & L_r & 0 \\ 0 & -L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \qquad (3)$$

- Equation of rotor

$$T_j \frac{d\omega_r}{dt} = M_m - M_e$$
$$M_e = L_M\left(i_{qs} i_{dr} - i_{ds} i_{qr}\right) \qquad (4)$$

where, $\lambda_{ds}, \lambda_{qs}, \lambda_{dr}, \lambda_{qr}$ are flux leakage for stator and rotor in d-q coordinates, L is induction, u, i are voltage and current, $\omega_1, \omega_2, \omega_r$ are angular speed for synchronous axis, slip and rotor which $\omega_r = \omega_1 - \omega_2$, and M_m, M_e are mechanical and electromagnetic torques.

In case of placing synchronously rotating d-q coordinates concurrently with stator voltage phasor along d-axis and flux phasor at q-axis the equation of voltage balance may be introduced in following form:

$$U_{dr} = R_r i_{dr} + \sigma L_r di_{dr}/dt - (\omega_1 - \omega_r)(L_m i_{qs} + L_r i_{qr})$$
$$U_{qr} = R_r i_{qr} + \sigma L_r di_{qr}/dt + (\omega_1 - \omega_r)(L_m i_{ds} + L_r i_{dr}) \qquad (5)$$

where, $\sigma = \frac{L_s L_r - L_m^2}{L_s L_r}$, $i_{ds} = -\frac{L_m}{L_s}$ and $M_e = \frac{L_m}{L_s}\lambda_s i_{dr}$.

B. Modeling of PV Solar Unit

In accordance with equivalent circuit in Figure 5 the produced current for every PV solar unit may be determined by equations [11, 20].

$$I_{pv} = n_{ph} - n_p I_{sat}\left[\exp\left(\left(\frac{q}{AkT}\right)\left(\frac{U_{pv}}{n_s} + I_{pv} R_s\right)\right) - 1\right]$$
$$I_{ph} = \left(I_{sso} + k_i (T - T_r)\right) \cdot \frac{S}{1000} \qquad (6)$$
$$I_{sat} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left(\left(\frac{qE_{gap}}{kA}\right) \cdot \left(\frac{1}{T_r} - \frac{1}{T}\right)\right)$$

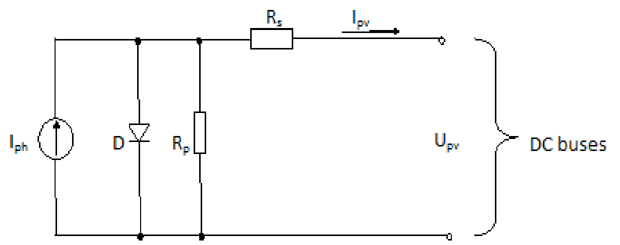

Figure 5. PV solar unit model

C. Modeling of Battery

In total description of hybrid system dynamics, the battery as source of DC current may be modeled as [21];

$$U_b = U_o + R_b i_b - K \frac{Q}{Q + \int i_b dt} + A \exp\left(B \int i_b dt\right)$$
$$CSB = 100\left(\frac{\int i_b dt}{Q}\right) \qquad (7)$$

where, U_b is nominal voltage of battery; CSB is charging state of battery; U_0 is battery voltage in off position; R_b is battery internal resistance; i_b is charge current; K is polarization voltage; Q is capacity; A is exponential voltage; and B is exponential capacity.

IV. STUDY OF HYBRID AC/DC MICROGRIDS OPERATION UNDER DIFFERENT OUTPUT FROM CONVENTIONAL AND RENEWABLE SOURCES AND LOADS

For detailed study of microgrid design model including renewable sources and two systems with AC and DC buses of the substituted electric network was composed. Design model for studied micro grid is concluded:

- Power system (GRID) having connection with micro grid trough the common point;
- Diesel generator, back operated, 70 kW;
- Wind turbine connected to AC system;
- PV solar power unit, 200 kW, connected to DC system;
- AC load, 80 kVA;
- DC load, 20 kW, mainly this load is modeled as electric lighting;
- Battery and charging equipment, connected to DC system.

Depending on output from wind turbine and PV solar set the micro grid rated modeling of operation was studied. Two case studies were implemented:

- Autonomous (isolated from GRID) operation;
- Working parallel with GRID.

The power flow in AC and DC system for isolated case and under wind turbine output is changing randomly and are shown in Figures 6 and 7. Some results of study under changing output from WT are given in the Table 1.

Connection between AC and DC networks is carried out by control of bidirectional invertors and that provides to manage both power production and consumption of power at the microgrid. Power Production and Consumption Control (PPCC) helps to provide condition then the main part of power consumption is covered by power generation from renewable.

The circuit uses 5 invertors which help to coordinate operation with GRID to support energy balance between generation and consumption at the AC-DC networks as a function of power produced by wind turbine and solar PV unit.

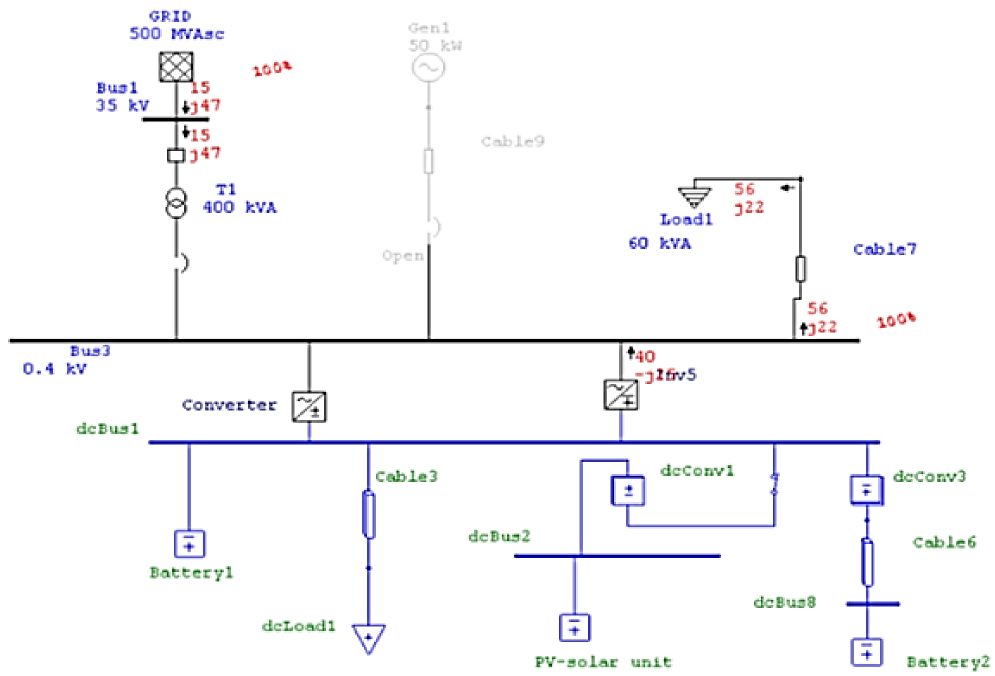

Figure 6. Power flow in AC system for isolated case and under wind turbine output

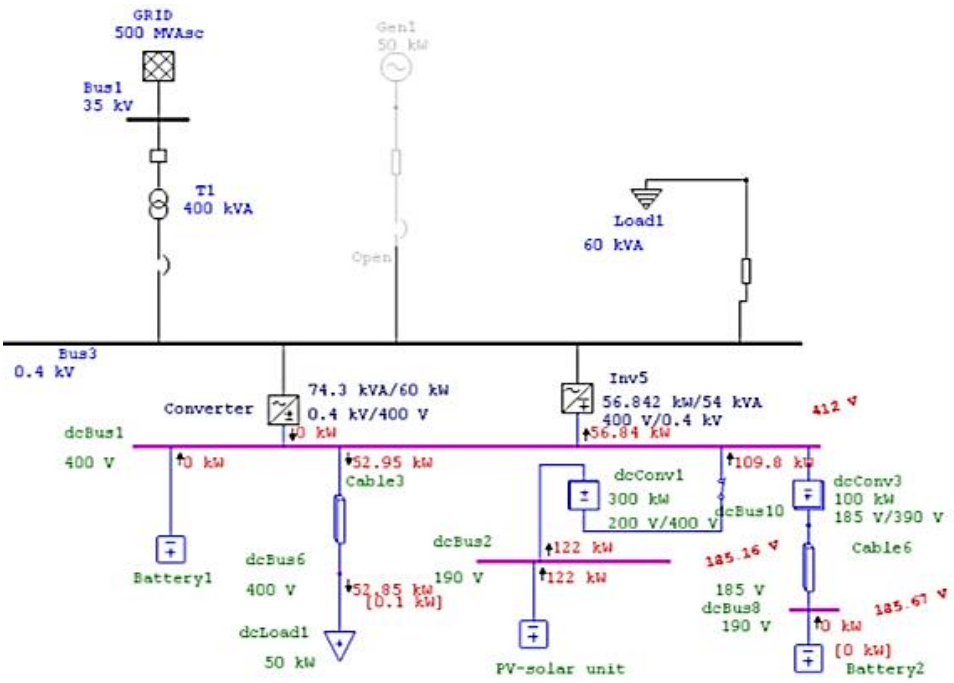

Figure 7. Power flow in DC system for isolated case and under wind turbine output

Table 1. Comparing wind energy with other energy resources regarding to total load demands covering

AC sources		DC sources		AC load	DC load	Microgrid interconnection	Change AC-DC
Wind generator	Diesel generator	PV aggregate	Battery				
200+*j*30	0	0	0	96+*j*58	85.7	0	102+*j*37
43+*j*30	25-*j*129	117.7	0	96+*j*58	81.12	0	-29-*j*94
0	25-*j*129	170.2	0	96+*j*58	81.12	0	-72-*j*188

V. REALIZATION OF CONTROL METHODS FOR AC/DC INVERTORS

The developed algorithm for power flow control between GRID and micro grid and also between AC and DC micro grids is carried out in the ETAP software format. Bidirectional inverter has to provide stability and voltage quality on AC bus. Inverters of WT and solar PV-units tuned to provide maximum power production to meet power demands of AC and DC loads. Fig. 8 demonstrates results of computer study then above mentioned conditions are satisfied for parallel operation of micro grid and GRID.

VI. CONCLUSION

Modern micro grids structures are involving a combination of resources, sometimes a quite complex one. The result of this work demonstrate that the operation of micro grids offers distinct advantages to customers and utilities, i.e. improved energy efficiency, minimization of overall consumption, reduced environmental impact, improvement of reliability of supply, network operation benefits as boss reduction, congestion relief, voltage control, and cost efficient electricity infrastructure replacement. Micro grids have been proposed as "novel distribution network architecture within smart grids concept".

REFERENCES

[1] S. Chowdhury, S.P. Chowdhury, P. Crossley, "Microgrids and Active Distribution Networks", The Institution of Engineering and Technology, Stevenag, UK, 2009.
[2] F. Katiraei, R. Iravani, N. Hatziargyrion, A. Dimeas, "Microgrids Management", IEEE Power and Energy Magazine, Vol. 6, No. 3, 2008.
[3] M. Ilic, J. Zaborsky, "Dynamics and Control of Large Electric Power Systems", Wiley & Sons, 2000.
[4] N.R. Rahmanov, G.B. Guliyev, "Fuzzy Logic Controller for Control of Reactive Power and Voltage in Distributed Generation Networks", Scientific and Technical Journal of Electrical Engineering, Electric Power Industry, and Electrotechnical Industry, No. 2, Moscow, Russia, 2014.
[5] Y. Zoka, H. Sasaki, N. Yorino, K. Kawahara, C.C. Lia, "An Interaction Problem of Distributed Generators Installed in a Microgrid", IEEE on Electric Utility Deregulation, Restructuring and Power Technologies Conference, Vol. 2, Hong Kong, 2004.
[6] D. Salomonsson, "Modeling, Control and Protection of Low Voltage DC Microgrids", Ph.D. Thesis, Royal Institute of Technology, School of Electrical Engineering, Electric Power Systems, Stockholm, Sweden, 2008.
[7] P. Savage, R.R. Nordhause, S.P. Jamieson, "DC Microgrids: Benefits and Barriers", Yale School of Forestry and Environmental Studies, 2010.
[8] M.E. Baran, N.R. Mahajou, "DC Distribution for Industrial Systems: Opportunities and Challenges", IEEE Trans. Ind. Appl., Vol. 39, No. 6, 2003.

[9] Y. Ito, Z. Yang, H. Akagi, "DC Microgrid Based Distribution Power Generation System", IEEE Int. Power Electron. Motion Control Conf., Vol. 3, 2004.
[10] D. Salomonsson, A. Sannino, "Low Voltage DC Distribution System for Commercial Power Systems with Sensitive Electronic Loads", IEEE Trans. on Power Del., Vol. 22, No. 3, 2007.
[11] N.R. Rahmanov, A.M. Hashimov, O.Z. Kerimov, "Effect of Combined Wind and Diesel Generation on Power System Operation", Renewable Energy World Conference, Milan, Italy, 2011.
[12] J. Lago, M.L. Heldwein, "Operation and Control Oriented Modeling of a Power Converter for Current Balancing and Stability Improvement of DC Active Distribution Networks", IEEE Transactions on Power Electronics, Vol. 26, No. 3, 2011.
[13] J.J. Justo, F. Mwasilu, A.C. Jung, "Microgrids Versus DC-Microgrids with Distributed Energy Sources: A Review", Renewable and Sustainable Energy Reviews, JW, No. 24, 2013.
[14] Microgrids Workgroup, "Large Scale Integration of Micro Generation to Low Voltage Grids", Target Action 1, Annex 1, Description of Work, Athens, Greece, 2002.
[15] R.H. Lasseter, "Microgrids", IEEE Power Engineering Society Winter Meeting, Vol. 1, pp. 305-308, New York, NY, USA, January 2002.
[16] P. Williams, G. Strback, "Costing and Pricing of Electricity Distribution Services", IEEE Power Engineering Journal, Vol. 15, No. 3, June 2001.
[17] A.M. Hashimov, N.R. Rahmanov, O.Z. Kerimov, "Integrated Hybrid Microgrid - The Cell of Future Distribution Network", 9th International Conference on Technical and Physical Problems in Electrical Engineering (ICTPE-2013), Istanbul, Turkey, 9-11 September 2013.
[18] Y. Li, D.M. Vilathgamuna, P.C. Loh, "Design, Analysis, and Real-Time Testing of a Controller for Multibus Microgrid System", IEEE Transactions on Power Electronics, Vol. 19, No. 5, 2004.
[19] N. Jenkins, R. Allan, P.C. Rossley, D. Kirschen, G. Strback, "Embedded Generation", The Institution of Electrical Engineers, UK, 2000.
[20] G. Venkataramanau, M. Illundala, "Microgrids and Sensitive Loads", IEEE Power Eng. Soc. Winter Meeting, Vol. 1, 2002.
[21] N.R. Rahmanov, N.M. Tabatabaei, K. Dursun, O.Z. Kerimov, "Combined AC-DC Microgrids: Case Study-Network Development and Simulation", 8th International Conference on Technical and Physical Problems of Electrical Engineering (ICTPE-2012), Fredrikstad, Norway, 5-7 September 2012.
[22] H.A. Shayanfar, G. Derakhshan, A. Ameli, "Optimal Operation of Microgrids Using Renewable Energy Resources", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 10, Vol. 4, No. 1, pp. 97-102, March 2012.
[23] H.A. Shayanfar, G. Derakhshan, A. Ameli, "Combined AC-DC Microgrids: Case Study - Network Development and Simulation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 12, Vol. 4, No. 3, pp. 157-161, September 2012.
[24] H.A. Shayanfar, G. Derakhshan, A. Ameli, "Optimum Management and Control of Smart Microgrid with Renewable DG", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 20, Vol. 6, No. 3, pp. 72-28, September 2014.
[25] H.A. Shayanfar, G. Derakhshan, A. Ameli, "Simulation of Steady State Operation for AC/DC Microgrid", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 21, Vol. 6, No. 4, pp. 22-29, December 2014.

BIOGRAPHIES

Nariman R. Rahmanov received the M.Sc. and Ph.D. degrees from Azerbaijan State Oil and Chemistry Institute (Baku, Azerbaijan) in 1960 and 1968, respectively. He received the Doctor of Technical Sciences in Power Engineering from Novosibirsk Electro Technical Institute, Russia in 1990. He is a Professor since 1990 and Director of Azerbaijan Scientific Research Institute of Energetic and Energy Design (Baku, Azerbaijan) from 2007 up to 2009, and Deputy Director of the same institute and SPII from 2009 up to present. He is Director of Azerbaijan-Norway Center of Cleaner Production and Energy Efficiency (CPEE Center). He is the member of IEEE, Academician of International Eco-Energy Academy (Baku, Azerbaijan), Co-Chairman of International Conference on "Technical and Physical Problems of Electrical Engineering" (ICTPE), member of Editorial Boards of International Journal on "Technical and Physical Problems of Engineering" (IJTPE) and Journal of Power Engineering Problems. His research areas are power systems operation and control, distributed systems, alternative energy sources. His publications are more than 210 articles and patents, and also 3 monographs.

Naser Mahdavi Tabatabaei was born in Tehran, Iran, 1967. He received the B.Sc. and the M.Sc. degrees from University of Tabriz (Tabriz, Iran) and the Ph.D. degree from Iran University of Science and Technology (Tehran, Iran), all in Power Electrical Engineering, in 1989, 1992, and 1997, respectively. Currently, he is a Professor in International Organization of IOTPE (www.iotpe.com). He is also an academic member of Power Electrical Engineering at Seraj Higher Education Institute (Tabriz, Iran) and teaches power system analysis, power system operation, and reactive power control. He is the General Chair and Secretary of International Conference of ICTPE, Editor-in-Chief of International Journal of IJTPE and Chairman of International Enterprise of IETPE all supported by IOTPE. He has authored and co-authored of 7 books and book chapters in Electrical Engineering area in international publishers and more than 150 papers in international journals and conference proceedings. His research interests are in the area of power system analysis and control, power quality, energy management systems, ICT in power engineering and virtual e-learning educational systems. He is a member of the Iranian Association of Electrical and Electronic Engineers (IAEEE).

Kamil M. Dursun was born in Ankara, Turkey, 1954. He received the M.Sc. and the Ph.D. degrees from The Norwegian Technical University, all in Power Electrical Engineering, in 1978 and 1984, respectively. He worked with ABB in several countries. Currently, he is a Professor of Power Engineering at Ostfold University College (Fredrikstad, Norway). He is the Secretary of International Conference of ICTPE. His research interests are in the area of efficient power distribution, energy management systems and virtual e-learning educational systems.

Zaur A. Mammadov was born in Azerbaijan. He is graduated from TEKNA, Oslo, Norway. He was Deputy Chairman of Management Board and Head of Strategic Development Department in AZENCO, Azerbaijan from 2010 to 2012. He is the Executive Director at Sumgait Chemical Industrial Park, Sumgait, Azerbaijan since 2012 till now.

Oktay Z. Kerimov graduated from Azerbaijan Industrial Institute (Baku, Azerbaijan) as a Mechanical Engineer in Automation Control. He received the Ph.D. degree from Moscow Institute of Power, Russia in 1970. He was Senior Researcher in Azerbaijan Institute of Power (Baku, Azerbaijan) from 1962 till 1981. He was a Visiting Scholar in UC Berkeley, CA, USA from 1977 till 1978. He also was an advisor on Power Systems in Park Holding, Turkey at the period of 1993-2004. At 2005 he joined again to Azerbaijan Institute of Power as the Head of Energy Saving and Efficiency Laboratory.