American Journal of Advanced Research, 2019, 3–2
December. 2019, pages 7-19
doi: 10.5281/zenodo.3371688
http://ibii-us.org/Journals/AJAR/
ISBN 2572-8849 (Online), 2572-8830 (Print)

Modeling of Energy Sources in Microgrid Using RSCAD/RTDS

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Received on 06/07/2019; revised on 07/05/2019; published on 08/19/2019

Abstract

Microgrid, an independent power grid, integrate the renewable energy sources like solar energy, wind energy, distributed energy sources like diesel generator, natural generator and energy storages like battery, ultra-capacitors are attracting many researchers across the world due to its high advantages like enhanced local energy delivery, efficiency, reliability, economic growth, etc. The microgrids have a capability to connect and disconnect to the traditional power grid and can operate independently; thus, a microgrid can operate in both grid connected and islanded modes. In this paper, a microgrid with renewable energy sources like solar energy, wind energy, and distributed energy sources like Lithium Ion battery (Li-Ion) energy storage, diesel generator, Polymer Electrolyte Membrane Fuel Cell, with power ratings of 1.8MW, 1MW, 400kW, 2MW, 10kW respectively. The microgrid is modeled and simulated using RSCAD/RTDS. The microgrid is rated a low-level voltage of 415V. The microgrid can be operated in both grid connected and islanded modes of operation. This paper discusses about the operation of microgrid in grid connected mode. In dq frame, a simplified PQ controller is implemented to control and stabilize the real and reactive power flow across the power grid. In 1.8MW solar energy, the PV array output voltage is reduced to 700V with the help of buck converter and then connected to the voltage source converter to convert the DC voltage to AC voltage of 415V. For wind energy of power rating 1MW, the induction generator provides an output voltage of 600V is reduced to 415V with the help of step-down transformer. Next, the Li-Ion battery energy storage of power rating 400kW is connected to the voltage source converter to convert the DC voltage to AC voltage of 415V. The diesel generator is connected to the power grid at 415V. The 11kW Polymer Electrolyte Membrane Fuel Cell (PEMFC) is connected to the voltage source converter to convert the DC voltage from the fuel cell to AC voltage of 415V. Then, the step-up transformer is used to increase the voltage of 415V from the energy sources to 0.48kV to connect to the power grid. A Line-Ground fault is inserted across the power grid and the effect of faults on microgrid is analyzed at various stages of the simulation. In conclusion, the microgrid operation in grid connected mode is analyzed using RSCAD simulation.

Keywords: Microgrid; Faults; RSCAD/RTDS; renewable energy sources; PQ controller

1 Introduction

Electric power grid is the largest system implemented to enable the quality of life of humans. High voltage AC is the most utilized method in the present era. [1-3]. But it has some constraints such as security, reliability and power quality. The fossil fuels depletion, low efficiency and environmental pollution has all led to the generation of power locally at distribution voltage level. Implementing the Distributed Energy Resources (DERs) like wind energy, solar energy, and Combined Heat and Power (CHP) can address the constraints of modern electric systems [4-6]. The integration of DERs into the utility grid enhances the energy efficiency, transmission and distribution assets utilization, power quality, reliability, etc. [10]. The microgrid is implemented to improve the bidirectional and controlled power flow in the distribution networks. A microgrid operates as a single power source with loads and is connected to the utility grid. It also provides the optimized efficiency for the power systems.

A microgrid is a low voltage supply network which can supply power to the local loads like schools, hospitals, industry, etc. A microgrid is an integration of DERs, critical and non-critical loads at a distribution voltage level. DERs can be renewable/non-conventional DERs and can generate power at the level of distribution voltage. The DERs are combined with power electronics and controls [1].

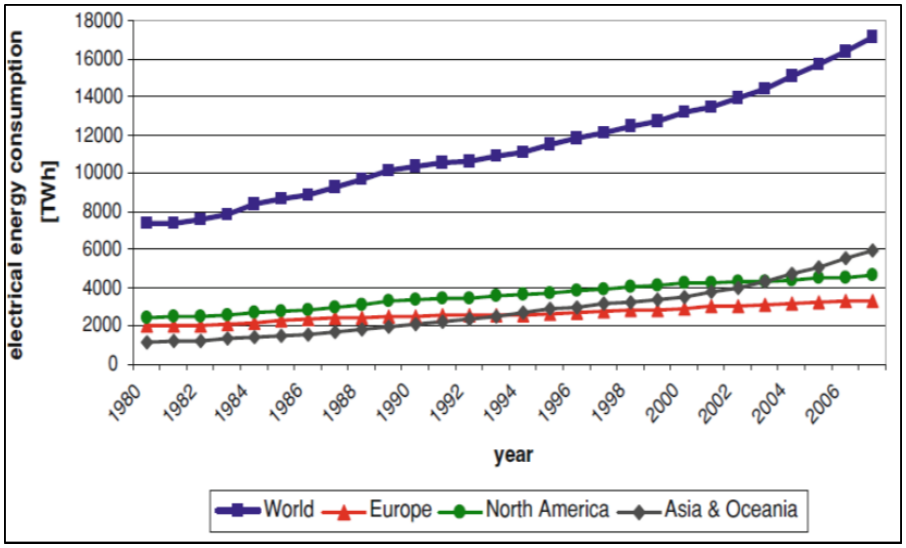


Fig. 1. Electrical Energy Consumption [1]

Fig.1. Illustrates the increase in the electrical energy consumption for a period of 27 years for the entire Europe, North America, Asia and Oceania, etc. regions [10].

2 Microgrid

Microgrid is an independent power grid which integrates the renewable energy sources like solar energy, wind energy, DERs like diesel generator, natural generator and energy storages like battery, ultra-capacitors, etc. along with the critical and non-critical loads. Microgrid is attracting many researchers and engineers across the world because of its immense benefits like improved efficiency, reliability, optimized cost operation, etc. [1-2]. They can connect and disconnect to the utility grid depending on its mode of operation – grid connected or islanded modes. The power quality at certain level and output energy of DERs are controlled by power electronic interfaces [2].

In a microgrid, the capacity of DERs is small compared to that of a conventional power plant with larger generators. The surplus power generated in a microgrid is fed into the utility grid [6-8]. A Point of Common Coupling (PCC) helps to connect the microgrid to the utility grid. A microgrid operate in grid connected and islanded mode; in the grid connected mode, the microgrid connects to the utility grid through PCC and exchanges power when required [20]. The microgrid shifts from the grid connected mode to the islanded mode during to the presence of transmission/distribution faults. In the islanded mode, the microgrid disconnects from the utility grid, generates and supply the power to the critical loads. This operation is coordinated and controlled by Microsource Controller and Central Controllers.

In this research, a microgrid with renewable energy sources like solar energy, wind energy, and distributed energy sources like Lithium Ion battery (Li-Ion) energy storage, diesel generator, Polymer Electrolyte Membrane Fuel Cell, with power ratings of 1.8MW, 1MW, 400kW, 2MW, 10kW respectively. The microgrid is modeled and simulated using RSCAD/RTDS. The microgrid is rated a low-level voltage of 415V.

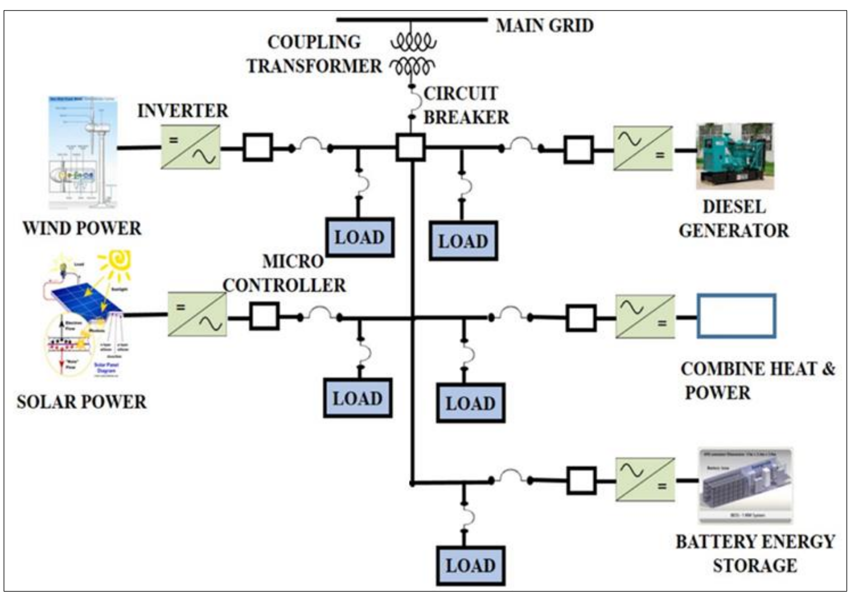


Fig. 2. A Typical Microgrid Structure Including Loads and DER Units Serviced by a Distribution System [1]

3 RSCAD/RTDS

RSCAD simulation tool, a real time power system simulation tool benefited her to perform all the necessary stages to run simulations, and later to analyze the simulation results across each stage of the experiment [9]. RSCAD tool aided her to create, control and analyze the real time operation of the energy sources in the microgrid. able to perform the analysis over a time step of 25-50µs for complex networks and 1-4 µs for small time step subnetworks. modeled a new fuel cell using RSCAD tool and integrated along with the other energy sources [9].

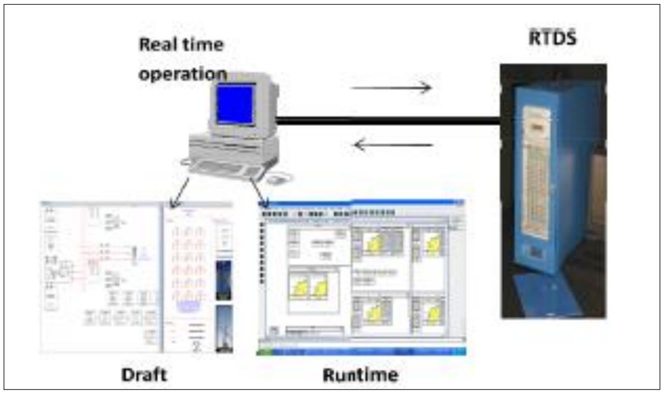


Fig.3. Layout of RSCAD/RTDS

4 Energy Sources

4.1 Solar – PV Array

The Solar PV array in this research consists of a PV panel with 36 cells in series and 1 cell in parallel. The open circuit voltage is 21.7V and short circuit current is 3.35A as mentioned in Fig.4. A monocrystalline silicon is used for the PV arrays. A buck converter is used decrease the voltage from the output of the PV Array and to enhance the Maximum Power Point Tracking (MPPT). The MPPT must be tracked to achieve the maximum value of solar array output power. The PV array considers the insolation (Watts/m2) and temperature (˚C) as inputs. The DC node voltages VDCp and VDCn as outputs [9].

Fig.5. shows the PV array connected to the buck converter and then to the DC/AC converter. DC/AC converter converts the DC voltage from the solar array to AC voltage. Then the AC voltage is connected to a 3-phase step-up transformer to increase the voltage of 230V to connect to the utility grid. The utility grid is connected to 0.48kV.

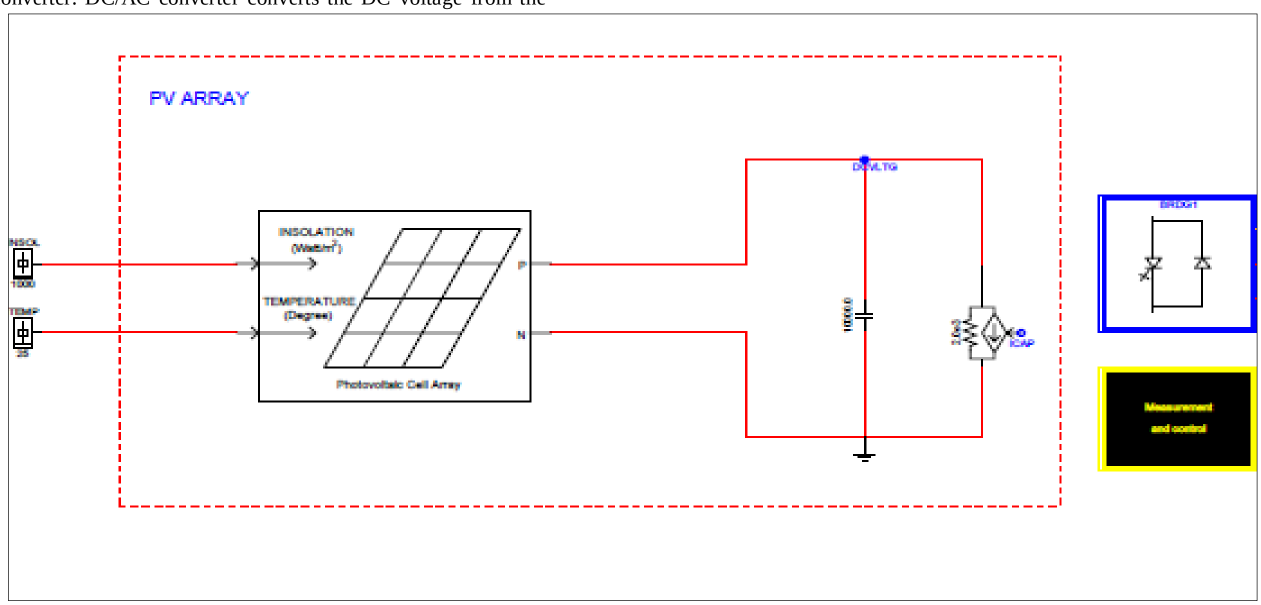


Fig. 4. Modeling of solar – PV array

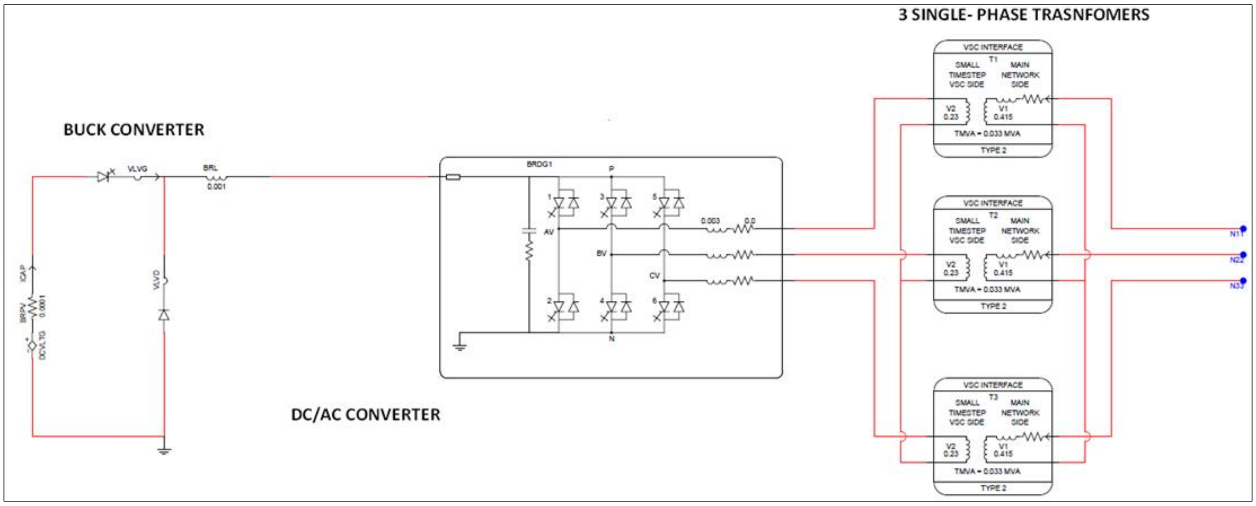
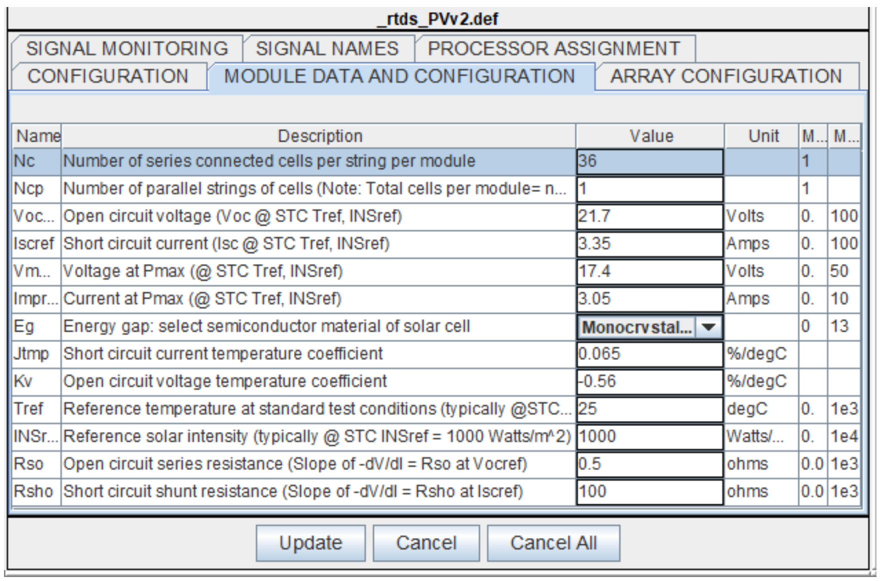


Fig. 5. DC/AC Converter

Fig.6. shows the parameters of the PV array.



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SIGNAL MONITORING | SIGNAL NAMES | PROCESSOR ASSIGNMENT
CONFIGURATION | MODULE DATA AND CONFIGURATION | ARRAY CONFIGURATION

Name	Description	Value	Unit	M...	M...
Nc	Number of series connected cells per string per module	36		1	
Ncp	Number of parallel strings of cells (Note: Total cells per module= n...	1		1	
Voc...	Open circuit voltage (Voc @ STC Tref, INSref)	21.7	Volts	0.	100
Iscref	Short circuit current (Isc @ STC Tref, INSref)	3.35	Amps	0.	100
Vm...	Voltage at Pmax (@ STC Tref, INSref)	17.4	Volts	0.	50
Impr...	Current at Pmax (@ STC Tref, INSref)	3.05	Amps	0.	10
Eg	Energy gap: select semiconductor material of solar cell	Monocrystal...		0	13
Jtmp	Short circuit current temperature coefficient	0.065	%/degC		
Kv	Open circuit voltage temperature coefficient	-0.56	%/degC		
Tref	Reference temperature at standard test conditions (typically @STC...	25	degC	0.	1e3
INSr...	Reference solar intensity (typically @ STC INSref = 1000 Watts/m^2)	1000	Watts/...	0.	1e4
Rso	Open circuit series resistance (Slope of -dV/dI = Rso at Vocref)	0.5	ohms	0.0	1e3
Rsho	Short circuit shunt resistance (Slope of -dV/dI = Rsho at Iscref)	100	ohms	0.0	1e3

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Fig. 6. PV Parameters

4.2 Wind Energy

A wind turbine with vertical axis is modeled using RSCAD as shown in Fig.7. The wind speed acts as an input to the vertical axis turbine. The kinetic energy in the wind is converted to the mechanical energy by the wind turbine which rotates the induction generator shaft. The wind turbine output power is based on the tip speed, pitch angle of the turbine blades, wind velocity and wind turbine blades area. The wind turbine efficiency is measured by the power coefficient of the wind turbine model [9].

The induction generator is rated at 1.8MVA base power, turns ratio of 1pu (per unit) and a stator rated voltage of 0.6kV. the generator rate revolution per minute (rpm) is 1200 rev/min. the wind generator is connected to the star-delta transformer to increase the voltage to 0.48kV of the utility grid.

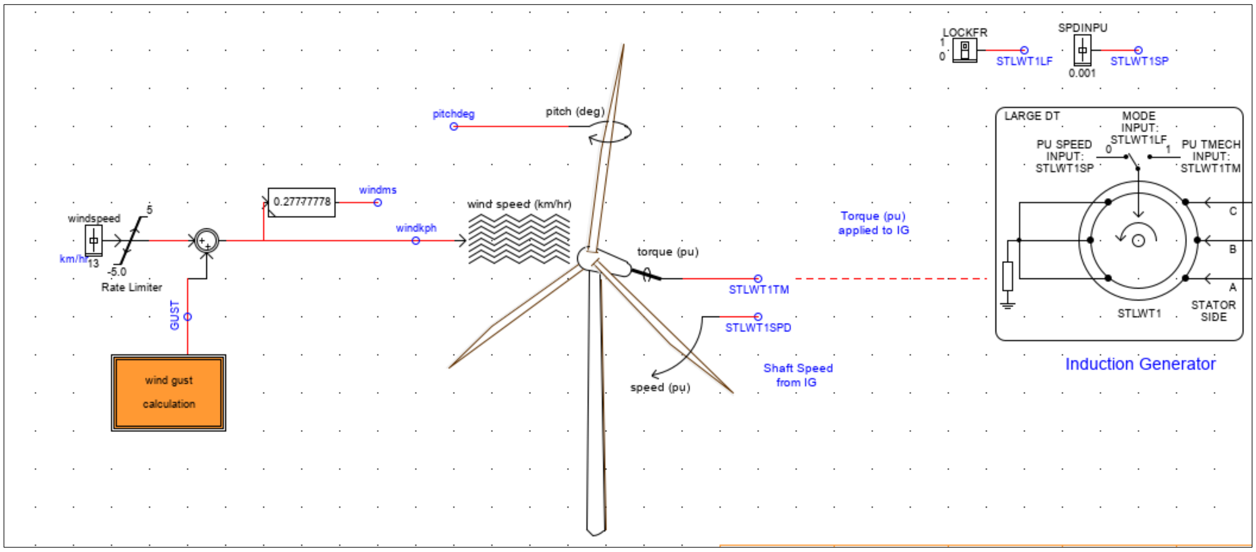


Fig. 7. Modeling of Wind Energy

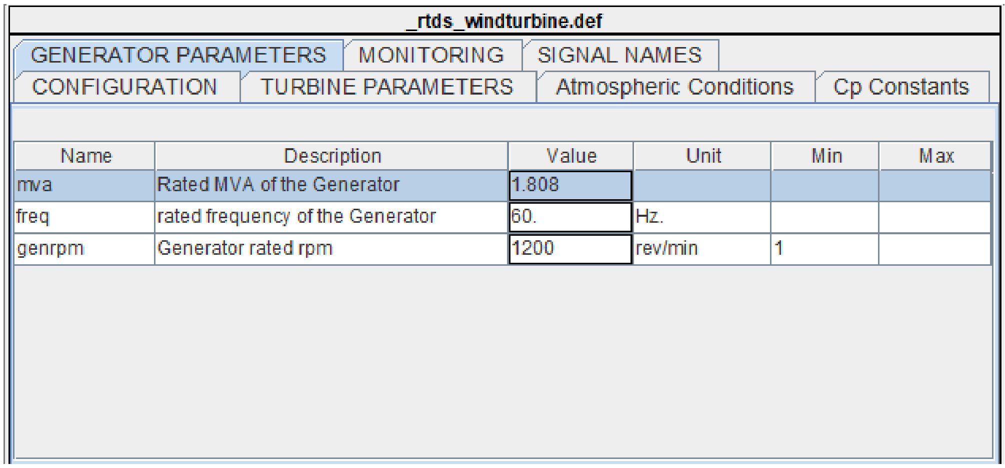
Fig. 8 and Fig.9. shows the parameters of induction generator and wind turbine respectively.

lf_rtds_risc_sld_INDM

SIGNAL NAMES FOR RUNTIME AND D/A | ENABLE MONITORING IN RUNTIME | ENABLE D/A OUTPUT | MACHINE SATURATION CURVE BY FACTORS | MONITORING OPTIONS | MOTOR ELECTRICAL PARAMETERS | MECHANICAL PARAMETERS | INITIAL CONDITIONS | LOAD FLOW | CONTROLS COMPILER INPUT | INDUCTION MACHINE CONFIGURATION | PROCESSOR ASSIGNMENT

Name	Description	Value	Unit	Min	Max
vbsll	Rated Stator Voltage (L-L RMS)	0.6	kV	0.01	
trato	Turns Ratio, Rotor over Stator	1.0	p.u.	0.01	
pbase	Rated MVA	1.808	MVA	0.0001	
hrtz	Rated Frequency	60.0	Hertz	5.0	150.0
ra	Stator Resistance	0.0077	p.u.	0.002	
xa	Stator Leakage Reactance	0.0697	p.u.	0.03	
xmd0	Unsaturated Magnetizing Reactance	3.454	p.u.	0.75	
rfd	First Cage Rotor Resistance	0.0062	p.u.	0.003	
xfd	First Cage Rotor Leakage Reactance	0.0834	p.u.	0.003	
rkd	Second Cage Rotor Resistance	0.2	p.u.	0.003	1.0e6
xkd	Second Cage Rotor Leakage Reactance	0.07	p.u.	0.0	1.0e6
xkf	Rotor Mutual Leakage Reactance	0.0	p.u.	0.0	1.0e6
rntrl	Neutral Resistance	5.0e4	p.u.	0.0	
xntrl	Neutral Reactance	0.0	p.u.		

Fig.8. Induction generator parameters



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GENERATOR PARAMETERS | MONITORING | SIGNAL NAMES | CONFIGURATION | TURBINE PARAMETERS | Atmospheric Conditions | Cp Constants

Name	Description	Value	Unit	Min	Max
mva	Rated MVA of the Generator	1.808			
freq	rated frequency of the Generator	60.	Hz.		
genrpm	Generator rated rpm	1200	rev/min	1	

Fig.9. Wind turbine parameters

4.3 Polymer Electrolyte Membrane Fuel Cell (PEMFC)

PEMFC is mainly used for the application is mainly used for the application of Electric Vehicles, grid technologies, etc. PEMFC is based on SR-12 from a company "ReliOn" (formerly called as Avista Labs) [10, 11]. PEMFC model has a cathode, anode and 3 control inputs - cell temperature (Tcell) in Celsius, the anode pressure (Pa) in atm, and cathode pressure (Pc) in atm. It also requires, parameters like charging capacitance per cell, cell area overall flow delay, rated voltage and current, and initial temperature and pressure values [9-11].

The PEMFC contains double layer charging capacitance per cell – 4.8F, cell area – 200cm2, overall flow delay in a stack – 240sec, rated current of 20A, rated voltage of 75V, initial cell temperature of 25C, initial anode and cathode pressure of 1.5 atm and 1 atm respectively. The number of cells in series and parallel in a stack are 144 and 8 respectively as shown in Fig.12. The output voltages in the form of cathode and anode from the fuel cell are connected to the full bridge converter and then to the DC/AC converter to convert to the AC voltage. Then the AC voltage is connected to a 3-phase step-up transformer to increase the voltage of 230V to connect to the utility grid as shown in Fig. 13. The utility grid is connected to 0.48kV [4].

Fig. 10 shows the modeling of PEMFC fuel cell and Fig.11 shows the simple PQ controller to control the DC/AC converter.

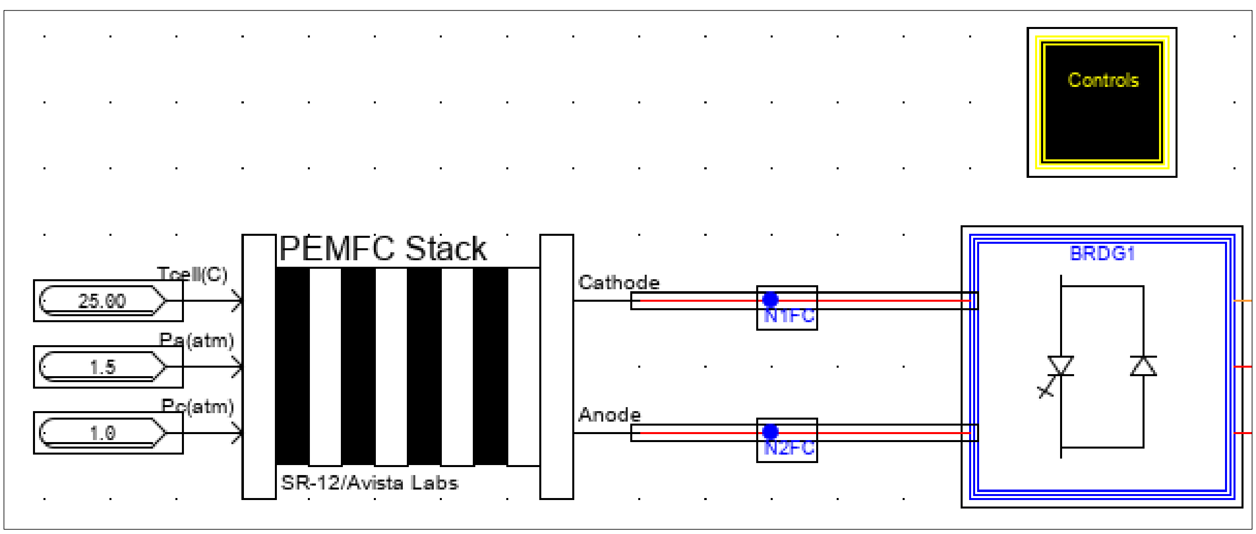


Fig.10. PEMFC modeling

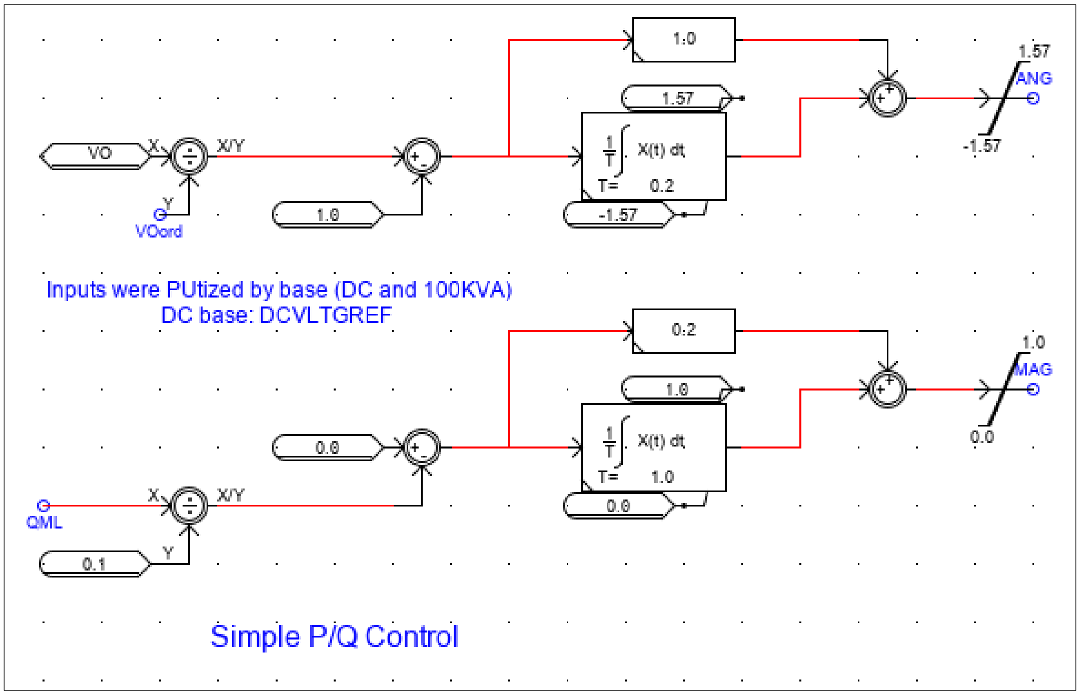
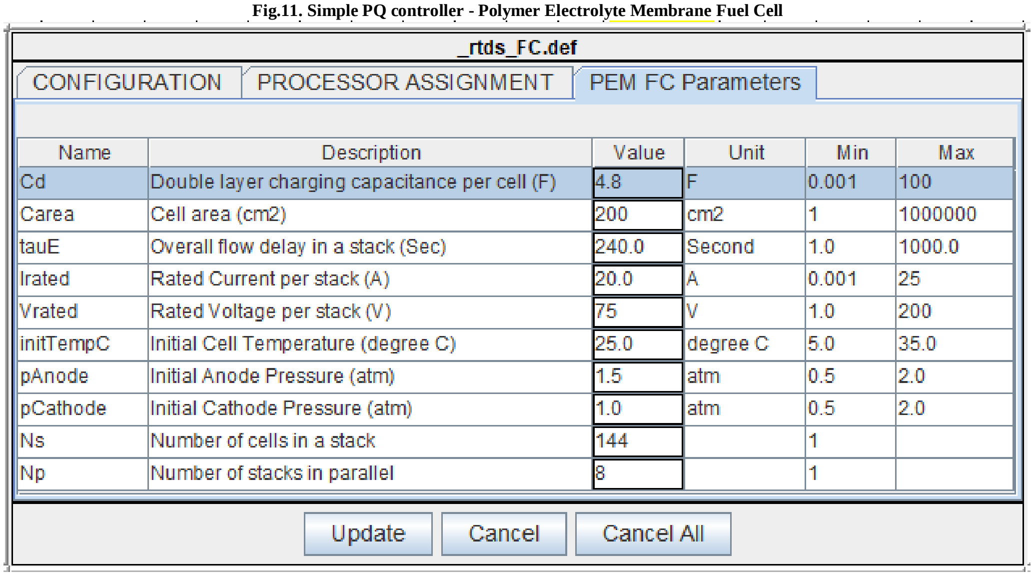


Fig.11. Simple PQ controller - Polymer Electrolyte Membrane Fuel Cell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CONFIGURATION | PROCESSOR ASSIGNMENT | PEM FC Parameters

Name	Description	Value	Unit	Min	Max
Cd	Double layer charging capacitance per cell (F)	4.8	F	0.001	100
Carea	Cell area (cm2)	200	cm2	1	1000000
tauE	Overall flow delay in a stack (Sec)	240.0	Second	1.0	1000.0
Irated	Rated Current per stack (A)	20.0	A	0.001	25
Vrated	Rated Voltage per stack (V)	75	V	1.0	200
initTempC	Initial Cell Temperature (degree C)	25.0	degree C	5.0	35.0
pAnode	Initial Anode Pressure (atm)	1.5	atm	0.5	2.0
pCathode	Initial Cathode Pressure (atm)	1.0	atm	0.5	2.0
Ns	Number of cells in a stack	144		1	
Np	Number of stacks in parallel	8		1	

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Fig. 12. PEMFC parameters

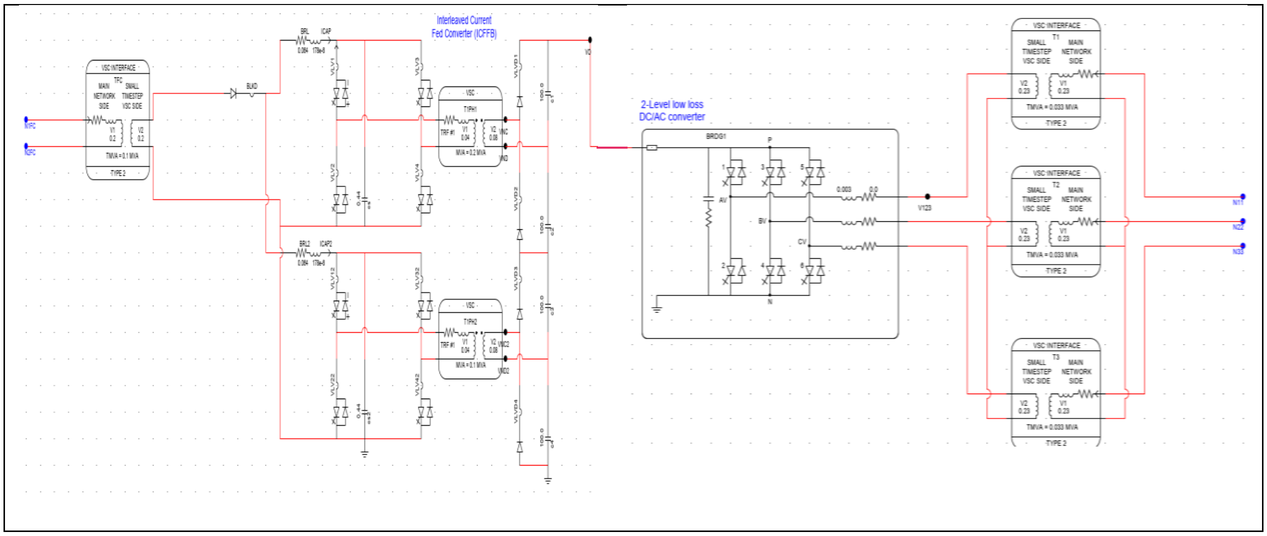

Fig.13. VSC converter

4.4 Lithium-Ion (Li-Ion) Battery Energy Storage

The parameters of the Li-ion battery are number of cells in series in a stack – 250, number of cells in parallel in a stack – 250. The output positive and negative voltages are connected to the connected to the full bridge converter and then to the DC/AC converter to convert to the AC voltage as shown in Fig.14. The DC/AC converter is controlled with the help of abc-dq frame controller as shown in Fig. 15. Then the AC voltage is connected to a 3-phase step-up transformer to increase the voltage of 230V to connect to the utility grid as shown in Fig. 13. The utility grid is connected to 0.48kV.

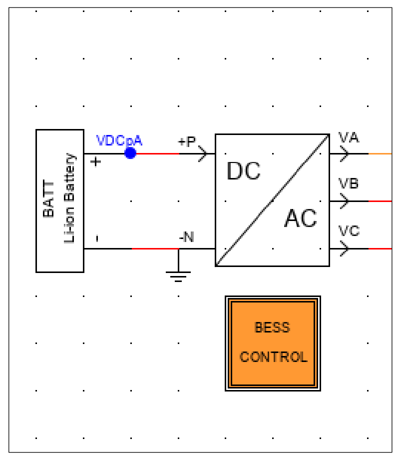

Fig.14. Modeling of Li-Ion battery

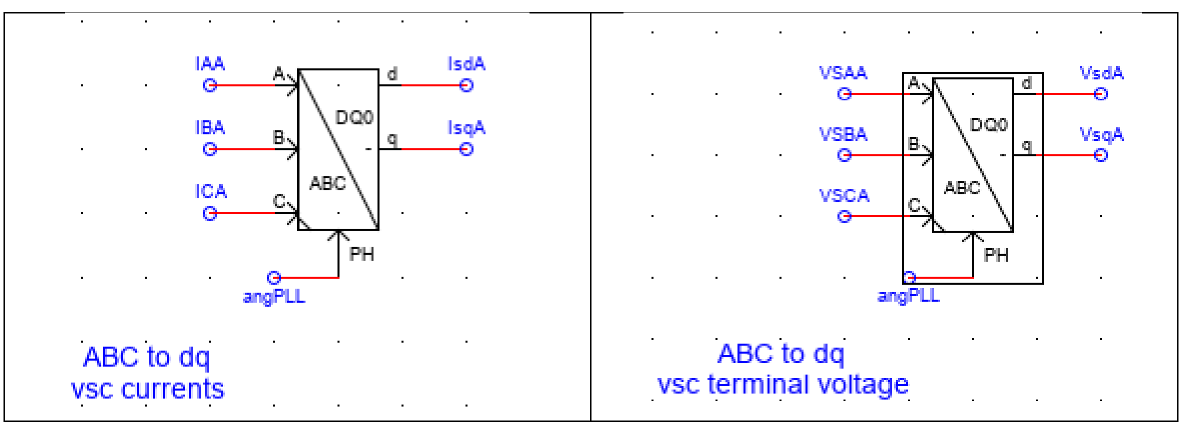

Fig 15. ABC to DQ frame

4.5 Diesel Generator

The Fig. 16 shows the modeling of diesel generator rated at 1.25MVA, line-line voltage of 0.48kV, 60Hz. Then the AC voltage is connected to the utility grid as shown in Fig. 16.

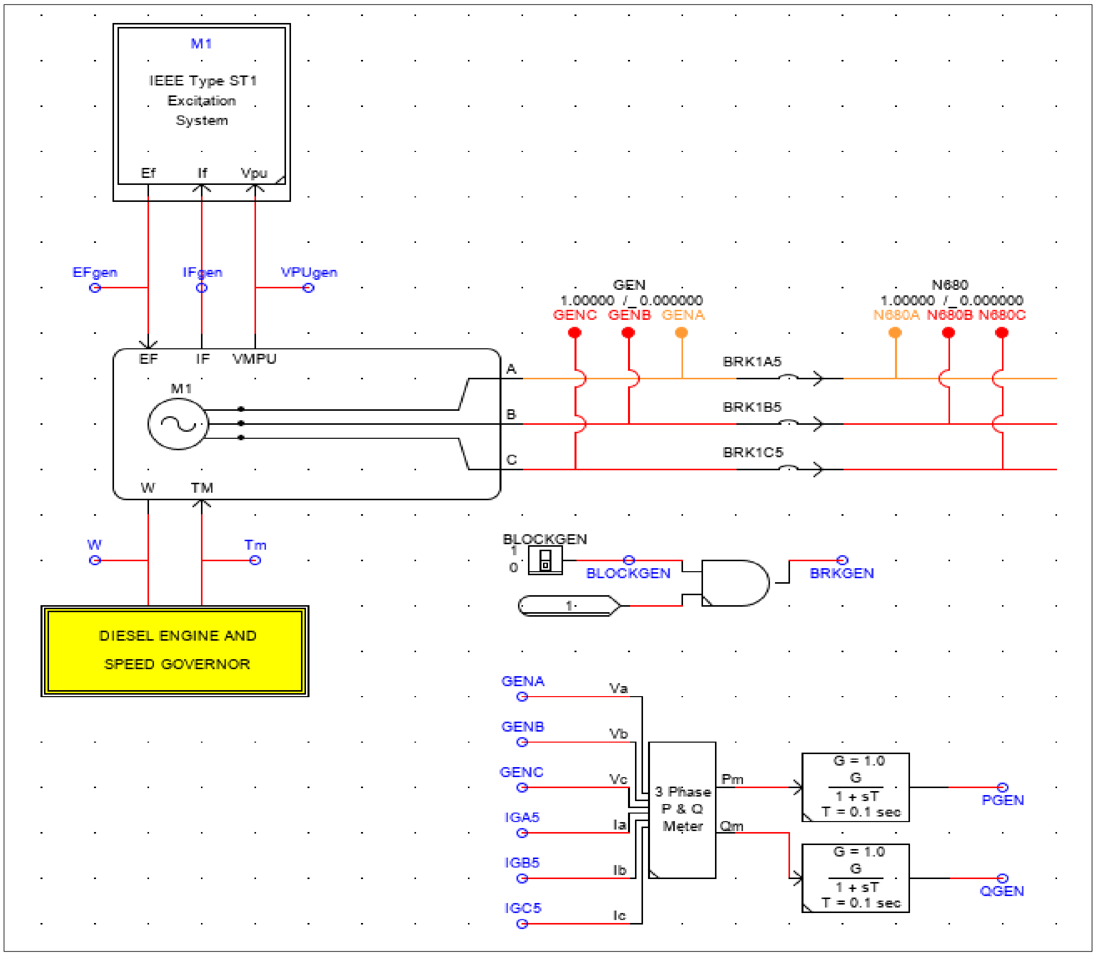

Fig.16. Modeling of Diesel Generator

5 Modeling of Energy Sources in Microgrid

This paper discusses about the operation of microgrid in grid connected mode. In dq frame, a simplified PQ controller is implemented to control and stabilize the real and reactive power flow across the power grid. The PQ controller controls the inverter's phase angle and amplitude. In 1.8MW solar energy, the PV array output voltage is reduced to 700V with the help of buck converter and then connected to the voltage source converter to convert the DC voltage to AC voltage of 415V. For wind energy of power rating 1MW, the induction generator provides an output voltage of 600V is reduced to 415V with the help of step-down transformer. Next, the Li-Ion battery energy storage of power rating 400kW is connected to the voltage source converter to convert the DC voltage to AC voltage of 415V. The diesel generator is connected to the power grid at 0.48kV. The 11kW Polymer Electrolyte Membrane Fuel Cell (PEMFC) is connected to the voltage source converter to convert the DC voltage from the fuel cell to AC voltage of 415V.

Then, the step-up transformer is used to increase the voltage of 415V from the energy sources to 0.48kV to connect to the power grid. A Line-Ground fault is inserted across the power grid and the effect of faults on microgrid is analyzed at various stages of the simulation. In conclusion, the microgrid operation in grid connected mode is analyzed using RSCAD simulation.

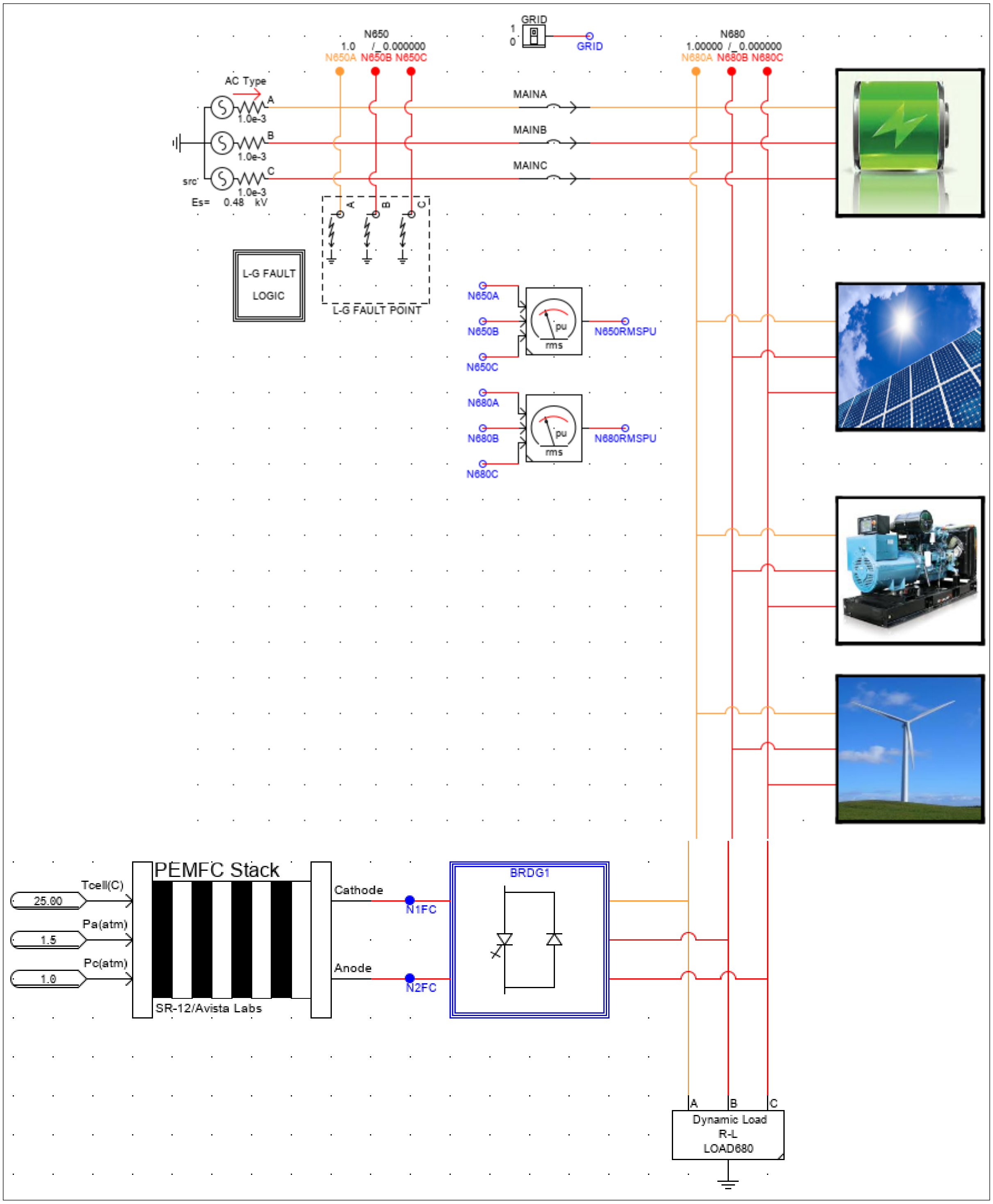

Fig.17. Modeling of microgrid in RSCAD

The Fig.17 shows the utility grid rated at 0.48kV connected to the microgrid. A Line to Ground fault is placed across the utility grid.

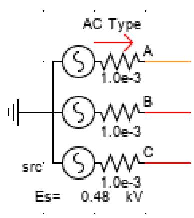

Fig.18. main grid/utility grid

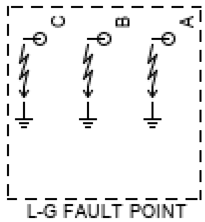

Fig.19. LG fault

Fig.18 shows the utility grid and Line to Ground fault in RSCAD. All the DERs consisting of DC/AC converter are controlled by simple PQ controller as shown in Fig.20.

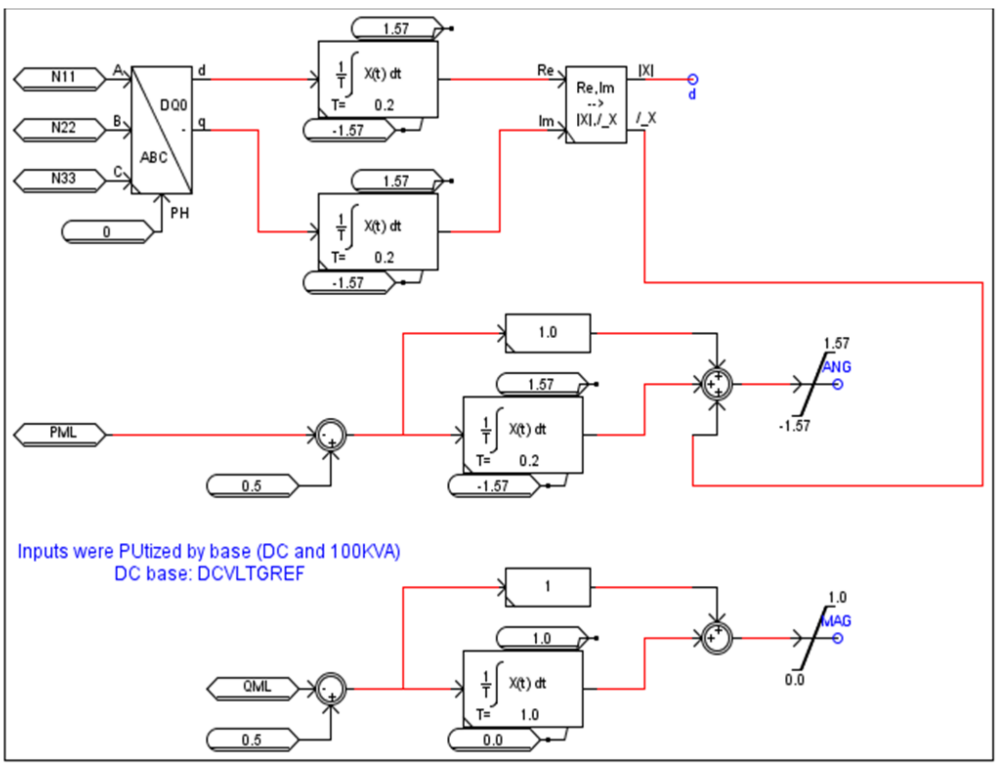

Fig. 20. Simplified PQ control

Fig.21 shows the 3-phase output voltage obtained across the PV array connect to the utility grid. Fig.22 illustrates the 3-phase output current obtained across the PV array. Fig.23 shows the 3-phase output voltage and current across the utility grid rated at 0.48kV.

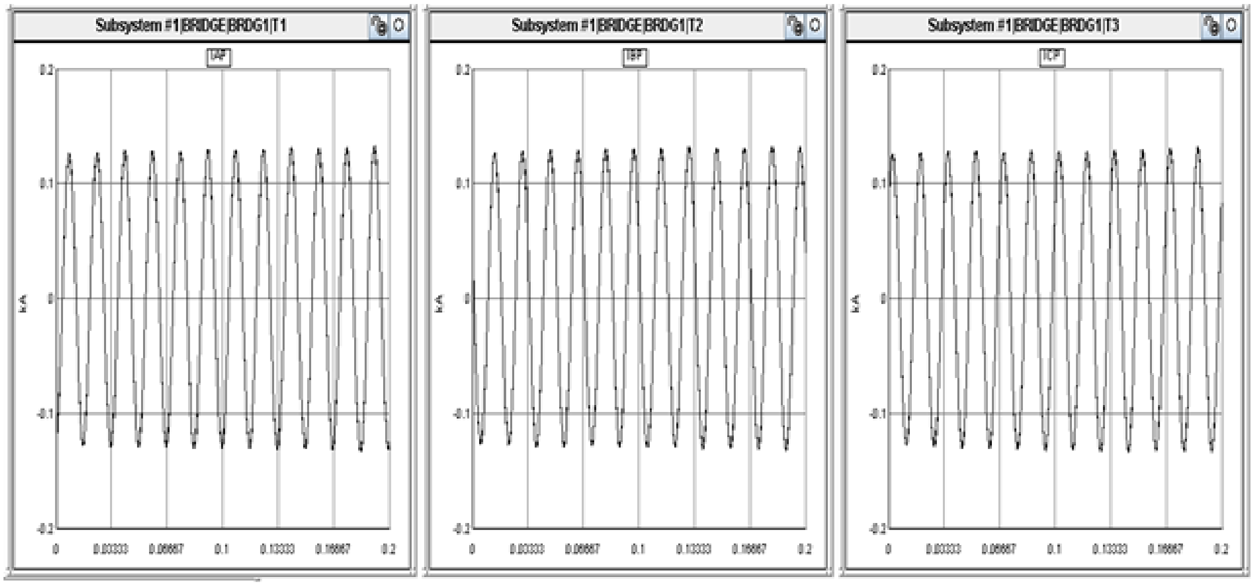

Fig. 21. Output voltage across SOLAR – PV ARRAY

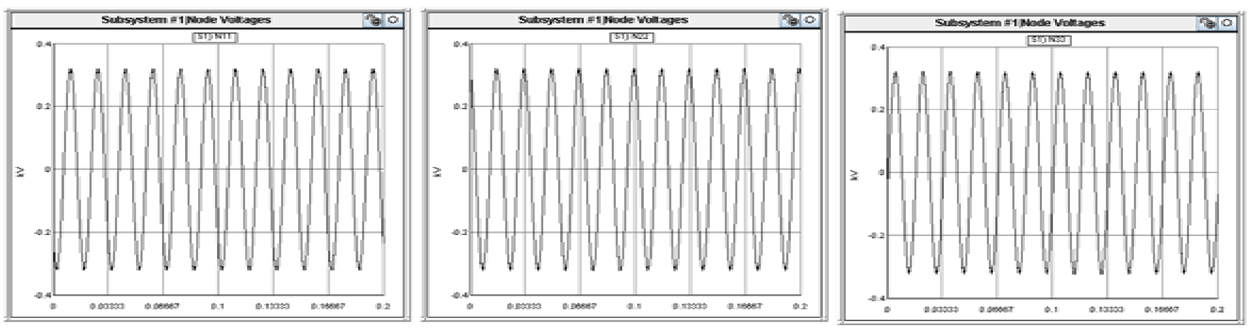

Fig.22. Output current

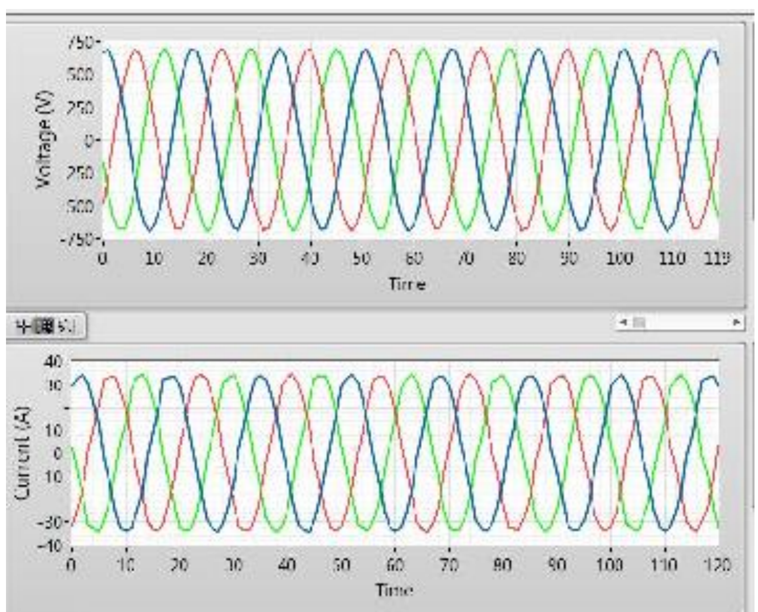

Fig 23. 3-phase output voltages and current across the power grid

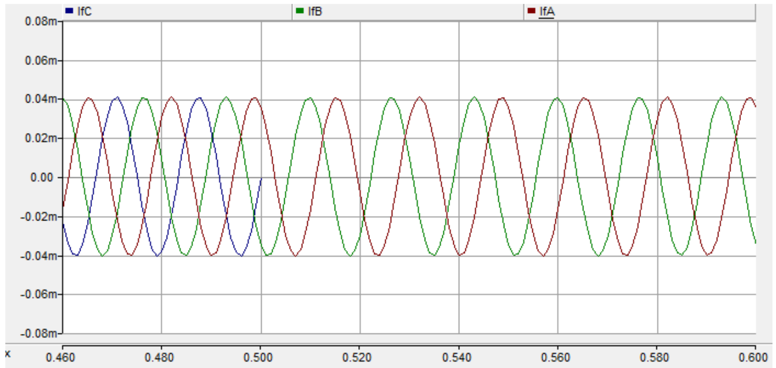

Fig. 24. 3-phase output currents across the power grid during the LG fault

The microgrid is connected to the power grid and modeling of the system is performed using RSCAD. A LG fault is inserted across the grid. The output currents across the power grid when a LG fault inserted are illustrated in Fig.24. The current across the phase C becomes 0 after 0.5 seconds of simulation, while the currents are phase A and B are obtained. The effect of the LG fault is studied and analyzed across the grid.

6 Conclusion

A microgrid with renewable energy sources like solar energy, wind energy, and distributed energy sources like Lithium Ion battery (Li-Ion) energy storage, diesel generator, Polymer Electrolyte Membrane Fuel Cell, with power ratings of 1.8MW, 1MW, 400kW, 2MW, 10kW respectively. The microgrid is modeled and simulated using RSCAD/RTDS. The microgrid can be operated in both grid connected and islanded modes of operation. This paper discusses about the operation of microgrid in grid connected mode. In dq frame, a simplified PQ controller is implemented to control and stabilize the real and reactive power flow across the power grid. The step-up transformer is used to increase the voltage of 415V from the energy sources to 0.48kV to connect to the power grid. A Line-Ground fault is inserted across the power grid and the effect of LG fault on microgrid is analyzed at various stages of the simulation. In conclusion, the microgrid operation in grid connected mode is analyzed using RSCAD simulation

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest: none declared.

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