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Research Article

MATLAB Simulation based Load Flow Analysis of a Photovoltaic Solar Energy Powered Ship

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Abstract

Ships are one of the major transportation used around the world. The Possibility of extinction of fossil fuels in near future and also the urge to reduce pollution, it is necessary to use renewable energy as an inevitable source. The primary aim of the present work is to promote clean and green energy for transportation. Major contributors of global warming are fossil fuel combustion. This paper suggests the use of solar energy in ships to produce electricity which improves reliability. In the present work, Primarily Load flow analysis of 18 bus ship electrical network is carried out in Matlab Simulink. Results obtained from load flow analysis are used to design a Solar PV Panel based on the load requirements. This model enhances the efficiency and reliability of shipboard power system to supply all electrical loads of ship.

Keywords: Solar energy; Load flow analysis; Array; Circuit; Modelling; Photo-Voltaic Panel.

Introduction

One of the major means of water transport used around the world is ships. Non-renewable energy sources like fossil fuels are used as fuels in ships to a greater extent. This causes many ecological problems to the environment such as global warming, air and water pollution. Protection of marine ecosystem is a primary responsibility of maritime industry. It is important to use clean energy source to reduce carbon emission. Hazardous gases like nitrogen, sulphur, CO_2 and hydrocarbons and discovered that ocean-going ships are the major contributors for pollution in marine environment [1]. For its benefits in fuel economy, ship operators use degraded oil. These pollutants are highly dangerous which depletes the ozone layer that leads to many detrimental effects on ecosystem Because of these reasons it is our responsibility to find an alternative source. Solar energy is the best choice of energy to use in marine ecosystem because of its clean and abundant nature.

The reasons for selecting solar energy as replacing energy source in marine industries are zero pollution, high reliability, elimination of dangerous byproducts, the cost of power from solar energy is less than stored energy from the grid, reduction in weight of the ship, longer lifetime and safer operation. Solar boat was designed to use in reserve areas and also proposed that using solar energy adds an advantage of instant power availability without a time delay in starting the engine and emergency stop is also possible [2,3]. In the present work, solar energy is used as primary source of energy which eventually reduces the fuel carried in ships thereby reducing the weight of the ship. This work enhances the efficiency of shipboard power system.

Analysis of electrical ship network

Baldwin and Lewis [4] examined 18 bus ship electrical radial networks. This Icebreaker ship line and bus data are taken for implementing this work. Load flow analysis of 18-Bus Radial Ship Electrical network is done in Matlab Simulink which provides the load requirement of ship.

Specification of 18 bus ship network

The present work analyzes the 18-bus ship electrical network which consists of four generators, six loads and four transformers as shown in Fig 1 based on the branch and bus data

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provided in Butler [5]. Four generators are connected to the buses 1, 2, 3, 4. Transformers are connected between the buses 7-8, 10-11, 13-14, 16-17 with tapping ratio 1 and six loads are connected to the buses 5, 6, 9, 11, 15, 18.

First bus is taken as slack bus. In this network, primary power source is four generators connected to buses 1, 2, 3 and 4.There are three Generator buses and fourteen load buses. Modelling is carried out with 10 MVA base power and 6600V of generation voltage. The Root mean square voltage level of the network is 4760V.

Tie line branch is 5-6. This network has four similar branches 9-7, 10-12, 13-15 and 16-18. The Branch and Bus data of 18-bus radial ship electrical network are tabulated in table 1 and table 2 respectively.

Table 1. Branch data of eighteen bus ship network

Start Bus	End bus	Branch type	Branch Resistance (PU)	Branch Reactance (PU)	Trans-former tap
1	5	L	0.000167	0.000208	-
2	5	L	0.000151	0.000188	-
3	6	L	0.000156	0.000195	-
4	6	L	0.000162	0.000202	-
5	6	L	0.000066	0.000082	-
5	7	L	0.000249	0.000310	-
8	9	L	0.000237	0.000408	-
9	10	L	0.000172	0.000215	-
11	12	L	0.000237	0.000408	-
6	13	L	0.000345	0.000430	-
14	15	L	0.000292	0.000502	-
6	16	L	0.000287	0.000358	-
17	18	L	0.000274	0.000470	-
7	8	T	0.020563	0.321954	1.0
10	11	T	0.020563	0.321954	1.0
13	14	T	0.020563	0.321954	1.0
16	17	T	0.020563	0.321954	1.0

Load flow analysis

Load flow analysis evaluates the steady state operating conditions of the network from the line and bus data provided. This network analysis results in voltage, phase angle, real and reactive power at each bus. Based on the sending and receiving end differences the line losses are calculated. This information helps to minimize the losses and to maintain stability of the system.

Table 2. Bus data of eighteen bus ship network

Bus No.	Bus type	Scheduled voltage (PU)	Scheduled generation (MW)	Scheduled load, P (MW)	Scheduled load, Q (Mvar)
1	Vδ	1.02	SLACK	0.00	0.00
2	PV	1.02	6.15	0.00	0.00
3	PV	1.02	6.04	0.00	0.00
4	PV	1.02	6.06	0.00	0.00
5	PQ	-	-	0.42	0.31
6	PQ	-	-	0.38	0.29
7	PQ	-	-	0.00	0.00
8	PQ	-	-	0.00	0.00
9	PQ	-	-	5.72	0.12
10	PQ	-	-	0.00	0.00
11	PQ	-	-	0.00	0.00
12	PQ	-	-	5.76	0.00
13	PQ	-	-	0.00	0.00
14	PQ	-	-	0.00	0.00
15	PQ	-	-	5.68	0.11
16	PQ	-	-	0.00	0.00
17	PQ	-	-	0.00	0.00
18	PQ	-	-	5.81	0.14

Newton-Raphson load flow method

Newton-Raphson load flow method gives more reliable results than any other power flow solution method on the basis of convergence rate, iteration count and memory usage for 18 bus radial ship electrical network. Power flow analysis of 18 bus ship network shown in fig. 1 is carried out in Matlab. It takes four iterations to converge. Load flow solutions and line flow losses are tabulated in table 3 and table 4 respectively. It is used as reference for the load flow solutions of Matlab/Simulink.

Modelling of solar panel

Han [6] said that the use of fossil fuels in shipping sectors affects ecosystem. He proposed an idea of using renewable energy sources in shipping sectors. The Practical Photovoltaic device exhibits hybrid behavior which can be fed as both voltage and current source. Thus this proposed approach increases the reliability of the network and also increases the efficiency of the system.

Hussein [7] and Ioannis [8] also said that PV technology is a cost effective solution for shipping industry. Yan [9] said that fuel consumption of diesel engine is reduced because of the use solar energy in ships. Kurniawan [10] also wrote in their work that use of renewable energy based technology may reduce the ship operation cost because of the uncertain price of oil. It has no rotating parts like wind turbine, which may affect ship stability. Solar panel is designed to deliver the power required by the network providing suitable values of series and parallel resistance values. The electrical generators are generally voltage or current source.

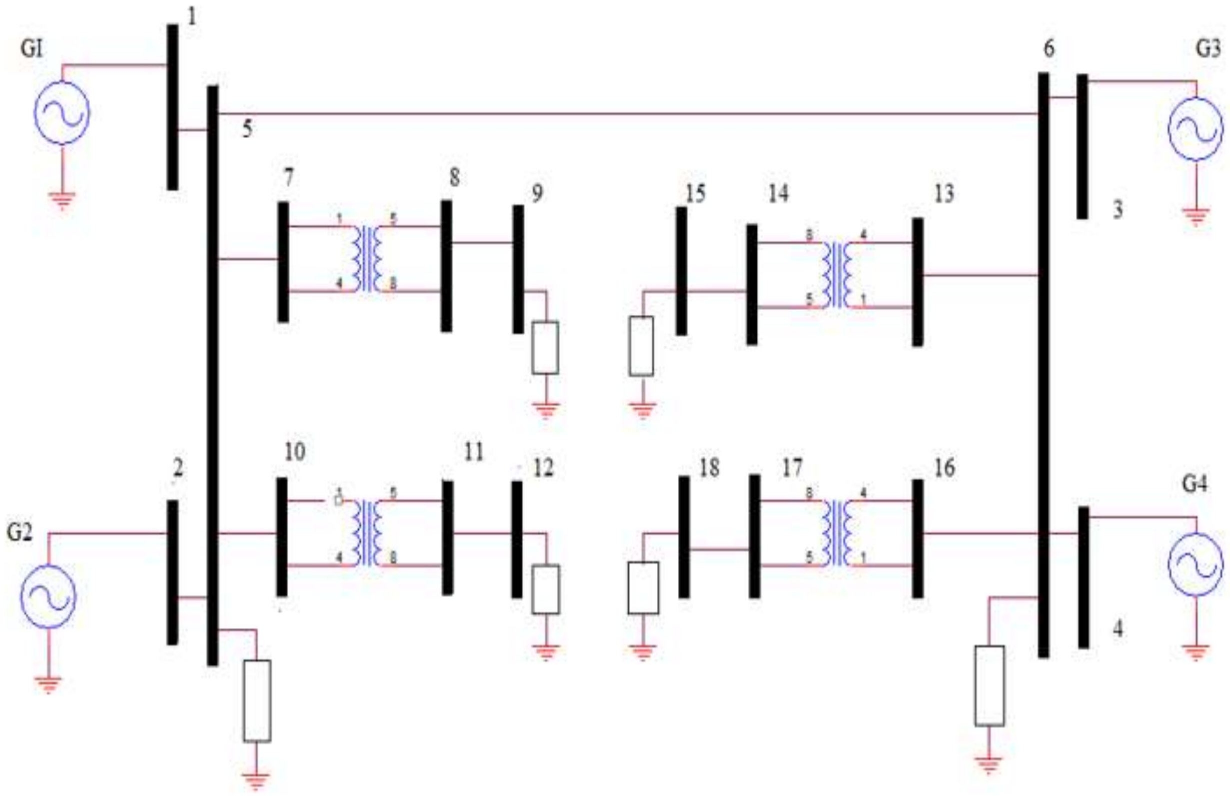

Fig. 1. Eighteen bus ship radial network

Calculation for solar panel

Modelling of solar panel requires calculation of voltage, current, maximum power required. Based on Villalva [11] photovoltaic panel is modelled in MATLAB/Simulink. It is also necessary to find the suitable value for Rs, Rp, Ns, Np, and Nss to meet the required load. The assumption Isc ≈ Ipv is generally used in photovoltaic models because in practical devices the series resistance is low and the parallel resistance is high. The Rs resistance is the sum of several structural resistances of the device. When the number of cells connected in series and parallel can be modified according to our requirement. Number of elementary series cells of the individual module is also changed to meet the required demand. The sudden change in load can be met by modifying the number of cells connected in series and parallel.

The present work aims at reducing the conventional energy source used in ships by modelling solar panel. Analysis is done in Matlab Simulink as shown in fig. 2. To provide the required power demand the following combinations of cells are connected. (a) Solar cells connected in series, Nss is 3. (b) Parallel connections of Solar cells, Npp is 1. (c) Number of elementary series cells of the individual module, Ns is 1. The voltage obtained from this combination is 0.984V. Based on the power requirement of 3.3 MVA, Ns is taken as 45.

Load flow analysis in Matlab Simulink

In Matlab Simulink, 18 bus ship network from fig. 1 is modelled and load flow analysis is done in simulation. In this network, there are eight similar branches with many six single phase loads and also generation is close to the demands. Based on the voltage, current and power required for the ship network, solar panels are designed. The results obtained are verified with load flow solutions obtained from Newton-Raphson method.

The maximum current that flows in the circuit is around 500A. Tie line current is around 35A. The Power rating of each generator is 3.3 MVA. The results obtained are verified by performing power flow analysis for the ship electrical network in Newton-Raphson load flow method in Matlab. Voltage at each bus of the ship electrical network is tabulated and the maximum per unit voltage obtained is 1.02. Since there are four similar branches, voltage at those buses are similar. Current flow at each branches are tabulated in table 5. The RMS voltage at each bus of ship electrical network is tabulated in table 6. MATLAB Simulation of 18 bus ship radial network is shown in fig. 3 and the results are tabulated in Table 5 and Table 6.

Table 3. Power flow solution by Newton-Raphson method

Power flow solution by Newton-Raphson Method							
Bus No.	Voltage Mag.	Angle Deg	Load MW	Load Mvar	Generation MW	Generation Mvar	Injected Mvar
1	1.020	0.000	0.00	0.00	5.808	1.218	0.00
2	1.020	-0.000	0.00	0.00	6.150	1.567	0.00
3	1.020	-0.000	0.00	0.00	6.040	1.447	0.00
4	1.020	0.000	0.00	0.00	6.060	1.202	0.00
5	1.020	-0.006	0.42	0.31	0.000	0.000	0.00
6	1.020	-0.005	0.38	0.29	0.000	0.000	0.00
7	1.020	-0.140	0.00	0.00	0.000	0.000	0.00
8	0.987	-10.536	0.00	0.00	0.000	0.000	0.00
9	0.987	-10.549	5.72	0.12	0.000	0.000	0.00
10	1.020	-0.011	0.00	0.00	0.000	0.000	0.00
11	0.987	-10.603	0.00	0.00	0.000	0.000	0.00
12	0.987	-10.616	5.76	0.09	0.000	0.000	0.00
13	1.020	-0.017	0.00	0.00	0.000	0.000	0.00
14	0.987	-10.460	0.00	0.00	0.000	0.000	0.00
15	0.987	-10.477	5.68	0.11	0.000	0.000	0.00
16	1.020	-0.015	0.00	0.00	0.000	0.000	0.00
17	0.985	-10.719	0.00	0.00	0.000	0.000	0.00
18	0.985	-10.735	5.81	0.14	0.000	0.000	0.00
Total loss			23.770	1.060	24.058	5.435	0.000

Table 4. Line flow losses

Line From	Line To	Power at bus and Line flow MW	Power at bus and Line flow Mvar	Line loss MW	Line loss Mvar	Trans-former Tap
1		5.808	1.218	5.935		
	5	5.808	1.218	5.935	0.001	0.001
2		6.150	1.567	6.347		
	6	6.150	1.567	6.347	0.001	0.001
3		6.040	1.447	6.211		
	6	6.040	1.447	6.211	0.001	0.001
4		6.060	1.202	6.178		
	6	6.060	1.202	6.178	0.001	0.001
5		-0.420	-0.310	0.522		
	1	-5.808	-1.217	5.934	0.001	0.001
	2	-6.149	-1.567	6.346	0.001	0.001
	6	-0.085	0.083	0.119	0.000	0.000
	7	5.791	1.204	5.915	0.001	0.001
	10	5.831	1.187	5.951	0.001	0.001
6		-0.380	-0.290	0.478		
	3	-6.039	-1.144	6.210	0.001	0.001
	4	-6.059	-1.201	6.177	0.001	0.001
	5	0.085	-0.083	0.119	0.000	0.000
	13	5.750	1.178	5.870	0.001	0.001
	16	5.884	1.262	6.017	0.001	0.001
7		0.000	0.000	0.000		
	5	-5.790	-1.203	5.914	0.001	0.001
	8	5.79	1.203	5.914	0.069	1.082
8		0.000	0.000	0.000		
	9	5.721	0.121	5.722	0.001	0.001
	7	-5.721	-0.121	5.722	0.069	1.082
9		-5.720	-0.120	5.721		
	8	-5.720	-0.120	5.721	0.001	0.001
10		0.000	0.000	0.000		
	5	-5.831	-1.186	5.950	0.001	0.001
	11	5.831	1.186	5.950	0.070	1.095
11		0.000	0.000	0.000		
	12	5.761	0.091	5.762	0.001	0.001
	10	-5.761	-0.091	5.762	0.070	1.095
12		-5.760	-0.090	5.761		
	11	-5.760	-0.090	5.761	0.001	0.001
13		0.000	0.000	0.000		
	6	-5.749	-1.177	5.868	0.001	0.001
	14	5.749	1.177	5.868	0.068	1.065
14		0.000	0.000	0.000		
	15	5.681	0.112	5.682	0.001	0.002
	13	-5.681	-0.112	-5.682	0.068	1.065
15		-5.680	-0.110	5.681		
	14	-5.680	-0.110	5.681	0.001	0.002
16		0.000	0.000	0.000		
	6	-5.883	-1.261	6.016	0.001	0.001
	17	5.883	1.261	6.016	0.072	1.120
17		0.000	0.000	0.000		
	18	5.811	0.142	5.813	0.001	0.002
	16	-5.811	-0.142	5.813	0.072	1.120
18		-5.810	-0.140	5.812		
	17	-5.810	-0.140	5.812	0.001	0.002
Total Loss				0.288	4.375	

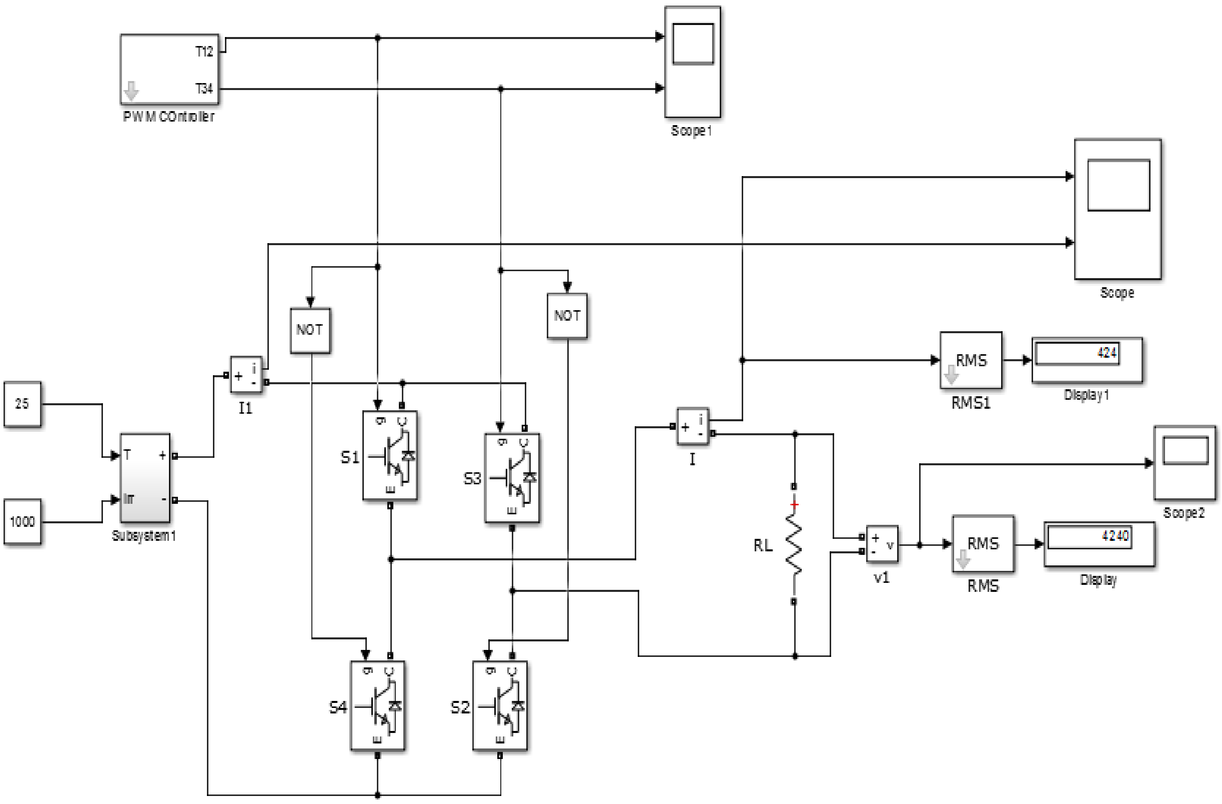

Fig. 2. Photovoltaic modelled with inverter circuit in MATLAB/Simulink

Table 5. Current profile of ship network

From bus	To bus	Current (A)
1	5	472.7
2	5	503.8
3	6	485.4
4	6	474.7
5	6	35.24
5	7	474.8
7	8	468.2
8	9	466.3
5	10	484.0
10	11	477.3
11	12	475.4
6	13	458.9
13	14	457.0
14	15	450.5
6	16	473.2
16	17	471.4
17	18	464.8

Table 6. Voltage profile of ship network

Bus No.	RMS voltage (V)	Per unit values
1	4776	1.020
2	4772	1.020
3	4762	1.020
4	4760	1.020
5	4708	1.010
6	4689	1.000
7	4651	0.990
8	4497	0.963
9	4487	0.961
10	4670	1.000
11	4515	0.970
12	4506	0.970
13	4607	0.990
14	4448	0.950
15	4435	0.950
16	4620	0.990
17	4455	0.950
18	4442	0.950

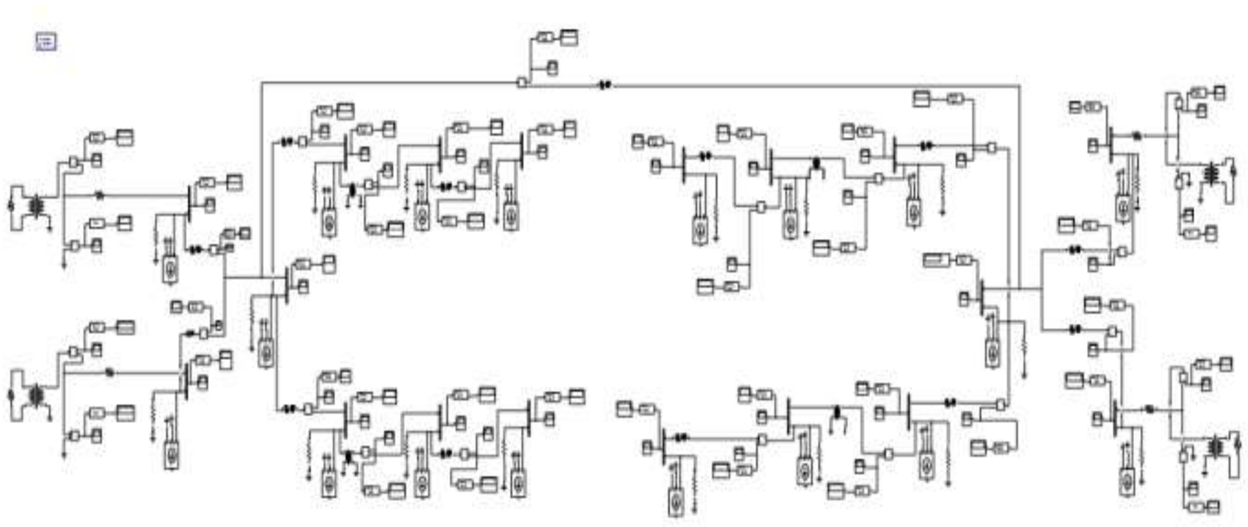

Fig. 3. Eighteen bus ship radial network in MATLAB/Simulink

Conclusion

In the present work, Load flow analysis of 18 bus radial ship electrical network is done Matlab Simulink and the total demand of the ship network is calculated and verified using Newton-Raphson power flow method. Based on the load demand, solar panels are designed. Thus this work promotes the use PV based solar energy for supplying all electrical loads of ships which eventually increases the efficiency and reliability of the network. This works aims at providing clean and green energy source for transportation in waterways.

Conflict of interest

Authors declare there are no conflicts of interest.

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