Analysis Of Electric Propulsion Performance On Submersible 60 M With Motor Dc 2x1850 Kw 380 V Using Ohmformer At Voltage 190 Vdc 10260 Ah And Without Using Ohmformer At Voltage 115 Vdc 10260 Ah

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***Abstract*—Electric propulsion system is ship propulsion system using electric motor to replace performance of main engine. Submersible ships use DC motor as electric propulsion system because DC motor has advantages of speed control and lower propulsion noise when submersible ship is at submerge condition.Design of electric propulsion system is using two DC motor thatare connected in series. Battery and generator as its power supply. Designs of electric propulsion system that will be reviewed hereare using ohmformerand without using ohmformer. Those designs will be simulated usingMATLAB Simulink.The results of the simulation are thatthe design using ohmformerisgreater in speed and power than without using ohmformer. Because of usingohmformer can control input voltage of DC motor thatuse generator as its power supply. Meanwhile, ohmformer-less design has constant input voltage that use battery as its power supply. Next, design of using ohmformer can be used for silent run (low speed), sailing run (medium speed) and quick run (high speed). Then design of without using ohmformer can be used for sailing run (medium speed).**

Keywords—Electric propulsion system, DC motor, Ohmformer, MATLAB

I. INTRODUCTION

The application of diesel engine as propulsion system have some problems and weaknesses. It is not able to operate when submersible ship is at submerge condition.To overcome those problems, alternative solution of ship propulsion is required. Electric propulsion can be used as this alternative solution.Electric propulsion system is the ship propulsion system using electric motor to replace performance of main engine. In general, special ship use DC motor for propulsion system and commercial ship use AC motor.

There are many attractive advantages for using electric propulsion for ships. There is lower propulsion noise and reduced vibration. Efficient performance and high motor torques, as the electrical system can provide maximum torque at low speed. Submersible ships use DC motor as electric propulsion system because DC motor has advantages of speed control and lower propulsion noise when submersible ship at submerge condition

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A. *Objectives*

Obtain difference characteristics between designof electric propulsion system using ohmformerand without using ohmformer.

1) Obtain required torque and rotation that be produced
2) Obtain speed and power of submersible that be produced
3) Determine efficient design of electrical propulsion system.

B. *Benefits*

The benefits of this thesisare to get characteristic data and performance of electrical propulsion. So that can be used in submersible ship.And,as learning stuff for the next research.

II. METHOD

A. *Study of Literature*

Learning about basic concept ofresistance and torque on submersible ship.Nextit isabout characteristic and speed control of DC motor. Then after that is about concept of electrical propulsion system.

B. *Empirical Studies*

Continuation learning based on sample already exists.There are principal dimension of submersible, design of electric propulsion and electrical component that be used.

C. *Data of Submersible*

Data of submersible used are shown in Table 1.

Table 1*Data of submersible*

Principal Dimension	
Length	59.7 meters
Inside Diameter	6.2 meters
Height	11.34 meters
Speed max	22 knots
Propeller	
Diameter	3.28 meters
Rotation max	200 rpm
Electric Propulsion	
Battery	480 cells (4 group); 2- 3 volt /cell; 10260 AH
DC Motor	Two of DC Motor Shunt; Double Armature; 2x1850 Kw; 380 V
DC Generator	480 KW; 1500 rpm; 340 V

D. Calculation of Resistance & Torque

It is necessary to know how much resistance a submersible faces in water, at a given speed, to decide power of motor to install on submersible. To calculate resistance of submersible use the following formula:

$$R_T = R_{BH} + R_{APP} \quad (N)$$
$$R_{BH} = \frac{1}{2}\rho x A x V^2 x C_t \quad (N)$$
$$R_{APP} = \frac{1}{2}\rho x A x V^2 x C_t \quad (N)$$

$R_T$is total resistance of submersible. $R_{BH}$is bare hull resistance and R_{APP} is appendages resistance.A is reference area (wetted area) of submersible. V is velocity of submersible. $C_T$is the non-dimensional drag coefficient. So, the total resistance of submersible is 138.433 kN.

After total resistance is known, then total required power can be calculated. To calculate the torque required on submersible use the following formula:

$$EHP = R_T \times V \quad (kW)$$
$$SHP = EHP/Pc \quad (kW)$$
$$\eta_m = PHP/SHP \quad (kW)$$
$$PHP = 2\pi n Q \quad (kW)$$
$$Q = PHP/2\pi n \quad (kNm)$$

EHP (effective horse power) is product of total resistance and the speed expressed in units of horsepower. SHP (shaft horse power) is power delivered by the propulsion device (electric motor). $\eta_m$is machinery efficiency. n is rotation of propeller. PHP (Propulsive horse power) is power delivered to the propulsor. And Q is torque required on submersible. So, total torque of submersible is 100.2804 kNm. That torque will be used as a load for motor DC when the simulation process is running.

E. Design of Electric Propulsion System

Figure 1 is design of electrical propulsion using ohmformerat voltage 190 VDC;10260 AH. That design can control input voltage to DC motor from generator.

Figure 2 is design of electric propulsion without ohmformer at 115 VDC;10260 AH. That design has constant voltage from battery. Both design use 2x1850 kW motor DC that are connected in series.

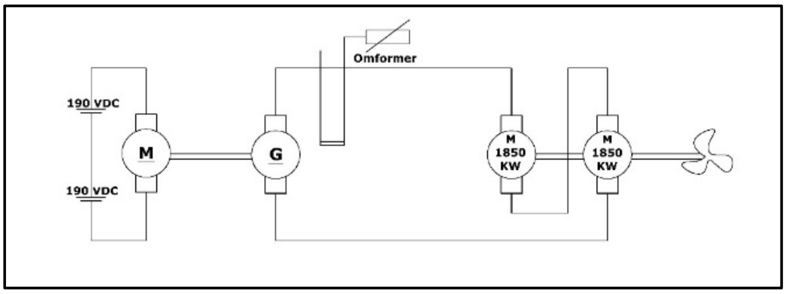

Figure 1*Design of using ohmformer*

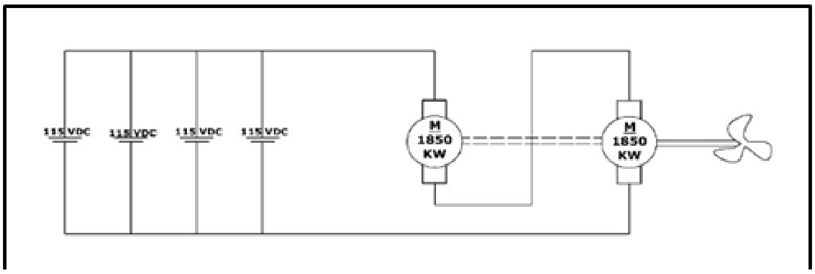

Figure 2*Design of wihtout using ohmformer*

F. Simulation Process

Design of electric propulsion (Figure 1&2) will be used to create model reference circuit in MATLAB Simulink. That model reference circuit shown in Figure 3&4.

Input of simulation is input voltage (10 – 340 V) for design using ohmformer and state of charge / SoC battery (100% - 5%) for designwithout using ohmformer. Input torque (100.2804 kNm) for both designs. Next, simulation will be processed.

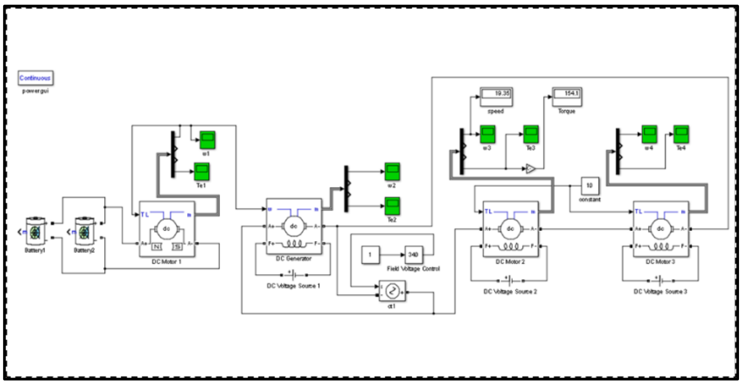

Figure 3*Design of using ohmformer in Simulink*

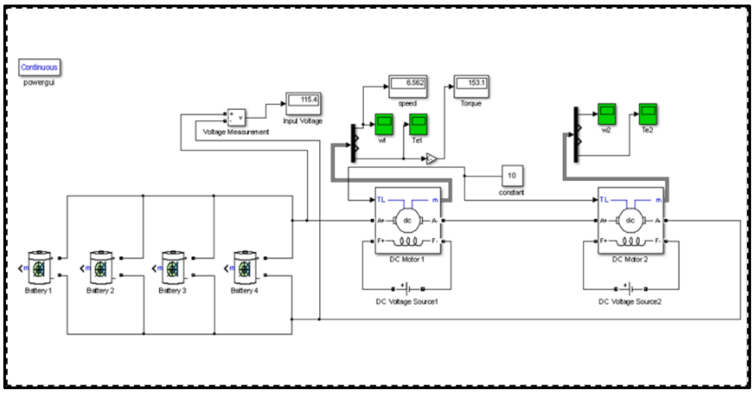

Figure 4*Design of without ohmformer in Simulink*

III. Results and Discussion

A. Result of Simulation

Table 2 is simulation data of design using ohmformer. Input of simulation is torque of submersible and input voltage.The function of ohmformer is to control input voltage to DC motor from generator. And the resultsare rotation and torque of motor.

Table 3 is simulation data of design without using ohmformer. Input of simulation is state of charge /SoC battery and torque of submersible. And the resultsare input voltage, rotation and torque of motor.

Table 2*Simulation data of design using ohmformer*

Torque of ship	Input voltage	Rotation of motor		Torque of motor
(kNm)	(Volt)	(rad/s)	(rpm)	(kNm)
100	10	0.56	5.348	153.7
100	20	1.13	10.791	153.7
100	30	1.69	16.138	153.7
100	40	2.26	21.581	153.7
100	50	2.83	27.025	15.37
100	60	3.41	32.563	153.7
100	70	3.97	37.911	153.7
100	80	4.54	43.354	153.7
100	90	5.11	48.797	153.7
100	100	5.68	54.240	153.7
100	110	6.25	59.683	153.7
100	120	6.82	65.126	153.7
100	130	7.39	70.569	153.7
100	140	7.96	76.012	153.7
100	150	8.53	81.455	153.7
100	160	9.1	86.899	153.7
100	170	9.67	92.342	153.7
100	180	10.24	97.785	153.7
100	190	10.81	103.228	153.7
100	200	11.38	108.671	153.7
100	210	11.95	114.114	153.7
100	220	12.52	119.557	153.7
100	230	13.09	125.000	153.7
100	240	13.66	130.443	153.7
100	250	14.23	135.886	153.7
100	260	14.8	141.330	153.7
100	270	15.37	146.773	153.7
100	280	15.94	152.216	154
100	290	16.51	157.659	154
100	300	17.08	163.102	154
100	310	17.65	168.545	154
100	320	18.22	173.988	154
100	330	18.78	179.336	154
100	340	19.35	184.779	154

Table 3*Simulation data of design withoutohmformer*

Torque of ship	SoC Battery	Input Voltage	Rotation of motor		Torque of motor
(kNm)	%	Volt	Rad/s	RPM	(kNm)
100	100%	115	6.562	62.662	153.1
100	90%	107	6.081	58.069	153.1
100	80%	107	6.076	58.022	153.1
100	70%	107	6.070	57.964	153.1
100	60%	107	6.063	57.897	153.1
100	50%	107	6.052	57.792	153.1
100	40%	106	6.036	57.640	153.1
100	30%	106	6.010	57.391	153.1
100	20%	104.8	5.970	57.009	153.1
100	10%	102.0	5.798	55.367	153.1
100	5%	96.4	5.480	52.330	153.1

B. *Speed (knots) & Brake Horse Power (BHP)*

Based on simulation data, speed and power of submersible can be calculated using following formula:

$Q = KQ \times d_{prop}^5 \times n^2$ (kNm)

$PHP = 2\pi \times Q \times n$ (kW)

$SHP = PHP / \eta_m$ (kW)

$BHP = SHP / 0,85$ (kW)

$Va = d_{prop} \times coefJ \times n$

$Vs = Va/(1-w)$ (m/s)

$Vs = Vs\ (m/s) \times 1.944$ (knot)

Table 4 is calculation data of design using ohmformer. The result is 0.5727 – 19.7 knots and 0.056 - 2306.850 kW. That calculation is based on variant of input voltage to motor DC.

Table 5 is calculation data of design without ohmformer. The result is 6.711– 5.605 knots and 77.445- 45.105kW. Thatcalculation is based on state of charge / Soc battery (%).

Table 4*Speed and power of design using ohmformer*

Input voltage	Rotation of motor		Q	PHP	SHP	BHP	Va	Vs	
(Volt)	(RPM)	(RPS)	(kNm)	(KW)	(KW)	(KW)		(m/s)	knot
10	5.348	0.089	0.0806	0.045	0.048	0.056	0.18856	0.2946	0.5727
20	10.791	0.180	0.3284	0.371	0.391	0.459	0.38048	0.5945	1.1557
30	16.138	0.269	0.7347	1.241	1.306	1.537	0.56904	0.8891	1.7284

Input voltage	Rotation of motor		Q	PHP	SHP	BHP	Va	Vs	
40	21.581	0.360	1.3138	2.968	3.124	3.675	0.76096	1.1890	2.3114
50	27.025	0.450	2.0602	5.827	6.134	7.217	0.95288	1.4889	2.8944
60	32.563	0.543	2.9912	10.195	10.731	12.625	1.14817	1.7940	3.4876
70	37.911	0.632	4.0543	16.088	16.934	19.923	1.33673	2.0886	4.0603
80	43.354	0.723	5.3021	24.059	25.326	29.795	1.52866	2.3885	4.6433
90	48.797	0.813	6.7170	34.307	36.113	42.485	1.72058	2.6884	5.2262
100	54.240	0.904	8.2991	47.116	49.595	58.347	1.91250	2.9883	5.8092
110	59.683	0.995	10.0484	62.771	66.075	77.735	2.10443	3.2882	6.3922
120	65.126	1.085	11.9648	81.559	85.852	101.002	2.29635	3.5880	6.9752
130	70.569	1.176	14.0484	103.765	109.227	128.502	2.48827	3.8879	7.5581
140	76.012	1.267	16.2991	129.676	136.501	160.589	2.68020	4.1878	8.1411
150	81.455	1.358	18.7170	159.575	167.974	197.617	2.87212	4.4877	8.7241
160	86.899	1.448	21.3020	193.751	203.948	239.939	3.06404	4.7876	9.3070
170	92.342	1.539	24.0542	232.487	244.723	287.909	3.25597	5.0875	9.8900
180	97.785	1.630	26.9736	276.070	290.600	341.882	3.44789	5.3873	10.473
190	103.228	1.720	30.0601	324.785	341.879	402.211	3.63982	5.6872	11.056
200	108.671	1.811	33.3137	378.918	398.862	469.249	3.83174	5.9871	11.639
210	114.114	1.902	36.7345	438.756	461.848	543.351	4.02366	6.2870	12.222
220	119.557	1.993	40.3225	504.582	531.139	624.870	4.21559	6.5869	12.805
230	125.000	2.083	44.0776	576.684	607.036	714.160	4.40751	6.8867	13.388
240	130.443	2.174	47.9999	655.347	689.839	811.575	4.59943	7.1866	13.971
250	135.886	2.265	52.0893	740.856	779.848	917.468	4.79136	7.4865	14.554
260	141.330	2.355	56.3459	833.497	877.365	1032.195	4.98328	7.7864	15.137
270	146.773	2.446	60.7696	933.556	982.691	1156.107	5.17520	8.0863	15.720
280	152.216	2.537	65.3605	1041.319	1096.126	1289.559	5.36713	8.3861	16.303
290	157.659	2.628	70.1186	1157.071	1217.970	1432.906	5.55905	8.6860	16.886
300	163.102	2.718	75.0438	1281.099	1348.525	1586.500	5.75098	8.9859	17.469
310	168.545	2.809	80.1361	1413.686	1488.091	1750.695	5.94290	9.2858	18.052
320	173.988	2.900	85.3956	1555.121	1636.969	1925.846	6.13482	9.5857	18.635
330	179.336	2.989	90.7257	1702.965	1792.595	2108.935	6.32338	9.8803	19.207
340	184.779	3.080	96.3165	1862.781	1960.822	2306.850	6.51530	10.180	19.790

Table 5*Speed and power of design without using ohmformer*

SoC Battery	Rotation of Motor		Q	PHP	SHP	BHP	Va	Vs	
%	RPM	RPS	(kNm)	(KW)	(KW)	(KW)		(m/s)	knot
100%	62.6625	1.0444	9.8361	64.5120	65.8285	77.4453	2.2095	3.4523	6.7113
90%	58.0693	0.9678	8.4470	51.3401	52.3878	61.6328	2.0475	3.1993	6.2194
80%	58.0215	0.9670	8.4331	51.2135	52.2587	61.4809	2.0458	3.1966	6.2143
70%	57.9642	0.9661	8.4165	51.0620	52.1041	61.2989	2.0438	3.1935	6.2081
60%	57.8974	0.9650	8.3971	50.8855	51.9240	61.0871	2.0415	3.1898	6.2010
50%	57.7923	0.9632	8.3666	50.6091	51.6419	60.7552	2.0378	3.1840	6.1897
40%	57.6396	0.9607	8.3224	50.2087	51.2334	60.2746	2.0324	3.1756	6.1734
30%	57.3913	0.9565	8.2509	49.5627	50.5742	59.4990	2.0236	3.1619	6.1468
20%	57.0093	0.9502	8.1414	48.5797	49.5711	58.3189	2.0101	3.1409	6.1059
10%	55.3668	0.9228	7.6791	44.5006	45.4088	53.4221	1.9522	3.0504	5.9299
5%	52.3301	0.8722	6.8598	37.5728	38.3396	45.1054	1.8452	2.8831	5.6047

C. Output Power of Motor (KW)

Based on simulation data, output power of motor can be calculated using following formula:

$$P = T \times \omega \quad (kW)$$

T istorque of motor (kNm) from simulation data and ω is angular speed (rad/s).

Table 6 is calculation data of output power using ohmformer. The result 86.072 – 2979.9 kW Thatcalculation is based on variant of input voltage to motor DC.

Table 7 is calculation data of output power without ohmformer. The result 1004.642-838.988kW. Thatcalculation is based on state of charge / Soc battery (%).

Table 6*Output power of motor of design using ohmformer*

Input voltage	Rotation of motor	Torque of motor	Output power of motor
(Volt)	(rad/s)	(kNm)	(KW)
10	0.56	153.7	86.072
20	1.13	153.7	173.681
30	1.69	153.7	259.753
40	2.26	153.7	347.362
50	2.83	153.7	434.971
60	3.41	153.7	524.117
70	3.97	153.7	610.189

80	4.54	153.7	697.798
90	5.11	153.7	785.407
100	5.68	153.7	873.016
110	6.25	153.7	960.625
120	6.82	153.7	1048.234
130	7.39	153.7	1135.843
140	7.96	153.7	1223.452
150	8.53	153.7	1311.061
160	9.1	153.7	1398.67
170	9.67	153.7	1486.279
180	10.24	153.7	1573.888
190	10.81	153.7	1661.497
200	11.38	153.7	1749.106
210	11.95	153.7	1836.715
220	12.52	153.7	1924.324
230	13.09	153.7	2011.933
240	13.66	153.7	2099.542
250	14.23	153.7	2187.151
260	14.8	153.7	2274.76
270	15.37	153.7	2362.369
280	15.94	154	2454.76
290	16.51	154	2542.54
300	17.08	154	2630.32
310	17.65	154	2718.1
320	18.22	154	2805.88
330	18.78	154	2892.12
340	19.35	154	2979.9

Table 7*Output power of motor of deisgn without using ohmformer*

SoC Battery %	Rotation of motor (rad/s)	Torque of motor (kNm)	Ouput power of motor (KW)
100%	6.554	153.1	1004.6422
90%	6.081	153.1	931.0011
80%	6.076	153.1	930.2356
70%	6.07	153.1	929.317
60%	6.063	153.1	928.2453
50%	6.052	153.1	926.5612
40%	6.036	153.1	924.1116
30%	6.01	153.1	920.131
20%	5.97	153.1	914.007
10%	5.798	153.1	887.6738
5%	5.48	153.1	838.988

D. Speed - Power Performance

Speed power performance is related withsubmersible resistance and torque, also power of submersible (BHP) and output power of motor. In this section will be calculated a comparison speed, power of submersible (BHP) and output power of motor. That can be calculated by using following formula:

RPM (%): (Rotation of motor / max. rotation of motor) x 100%

BHP (%): (BHP of submersible / output power ofmotor) x 100%

Table 8 is calculation data of design using ohmformer. Table 9 is calculation data of design without using ohmformer.

Table 8*Speed power performance of design using ohmformer*

Input voltage (Volt)	Rotation of motor (RPM)	Vs (Knot)	BHP (KW)	Ouput power of motor (KW)	RPM (%)	BHP (%)
10	5.348	0.573	0.056	86.072	2.67%	0.06%
20	10.791	1.156	0.459	173.681	5.40%	0.26%
30	16.138	1.728	1.537	259.753	8.07%	0.59%
40	21.581	2.311	3.675	347.362	10.79%	1.06%
50	27.025	2.894	7.217	434.971	13.51%	1.66%
60	32.563	3.488	12.625	524.117	16.28%	2.41%
70	37.911	4.060	19.923	610.189	18.96%	3.27%
80	43.354	4.643	29.795	697.798	21.68%	4.27%
90	48.797	5.226	42.485	785.407	24.40%	5.41%
100	54.240	5.809	58.347	873.016	27.12%	6.68%
110	59.683	6.392	77.735	960.625	29.84%	8.09%

120	65.126	6.975	101.002	1048.234	32.56%	9.64%
130	70.569	7.558	128.502	1135.843	35.28%	11.31%
140	76.012	8.141	160.589	1223.452	38.01%	13.13%
150	81.455	8.724	197.617	1311.061	40.73%	15.07%
160	86.899	9.307	239.939	1398.670	43.45%	17.15%
170	92.342	9.890	287.909	1486.279	46.17%	19.37%
180	97.785	10.473	341.882	1573.888	48.89%	21.72%
190	103.228	11.056	402.211	1661.497	51.61%	24.21%
200	108.671	11.639	469.249	1749.106	54.34%	26.83%
210	114.114	12.222	543.351	1836.715	57.06%	29.58%
220	119.557	12.805	624.870	1924.324	59.78%	32.47%
230	125.000	13.388	714.160	2011.933	62.50%	35.50%
240	130.443	13.971	811.575	2099.542	65.22%	38.65%
250	135.886	14.554	917.468	2187.151	67.94%	41.95%
260	141.330	15.137	1032.195	2274.760	70.66%	45.38%
270	146.773	15.720	1156.107	2362.369	73.39%	48.94%
280	152.216	16.303	1289.559	2454.760	76.11%	52.53%
290	157.659	16.886	1432.906	2542.540	78.83%	56.36%
300	163.102	17.469	1586.500	2630.320	81.55%	60.32%
310	168.545	18.052	1750.695	2718.100	84.27%	64.41%
320	173.988	18.635	1925.846	2805.880	86.99%	68.64%
330	179.336	19.207	2108.935	2892.120	89.67%	72.92%
340	184.779	19.790	2306.850	2979.900	92.39%	77.41%

Table 9*Speed power performance of design without usingohmformer*

SoC Battery	Rotation of motor	Vs	BHP	Ouput power of motor	RPM %	BHP %
%	(RPM)	knot	(kw)	(kw)		
100%	62.6625	6.7113	77.4453	1004.6422	31.33%	7.71%
90%	58.0693	6.2194	61.6328	931.0011	29.03%	6.62%
80%	58.0215	6.2143	61.4809	930.2356	29.01%	6.61%
70%	57.9642	6.2081	61.2989	929.3170	28.98%	6.60%
60%	57.8974	6.2010	61.0871	928.2453	28.95%	6.58%
50%	57.7923	6.1897	60.7552	926.5612	28.90%	6.56%
40%	57.6396	6.1734	60.2746	924.1116	28.82%	6.52%
30%	57.3913	6.1468	59.499	920.1310	28.70%	6.47%
20%	57.0093	6.1059	58.3189	914.0070	28.50%	6.38%
10%	55.3668	5.9299	53.4221	887.6738	27.68%	6.02%
5%	52.3301	5.6047	45.1054	838.9880	26.17%	5.38%

E. Analysis of Graph using ohmformer

Figure 5 is graph showing the relationship between input voltage to DC motor with speed of submersible. That graph is based on Table 4. Speed of submersible is directly proportional to input voltage. The increase of input voltage will be followed the increase of speed.

Figure 6 is graph showing speed power performance prediction of design using ohmformer. That graph is based on Table 8. Power of submersible (BHP) is related with power of motor.

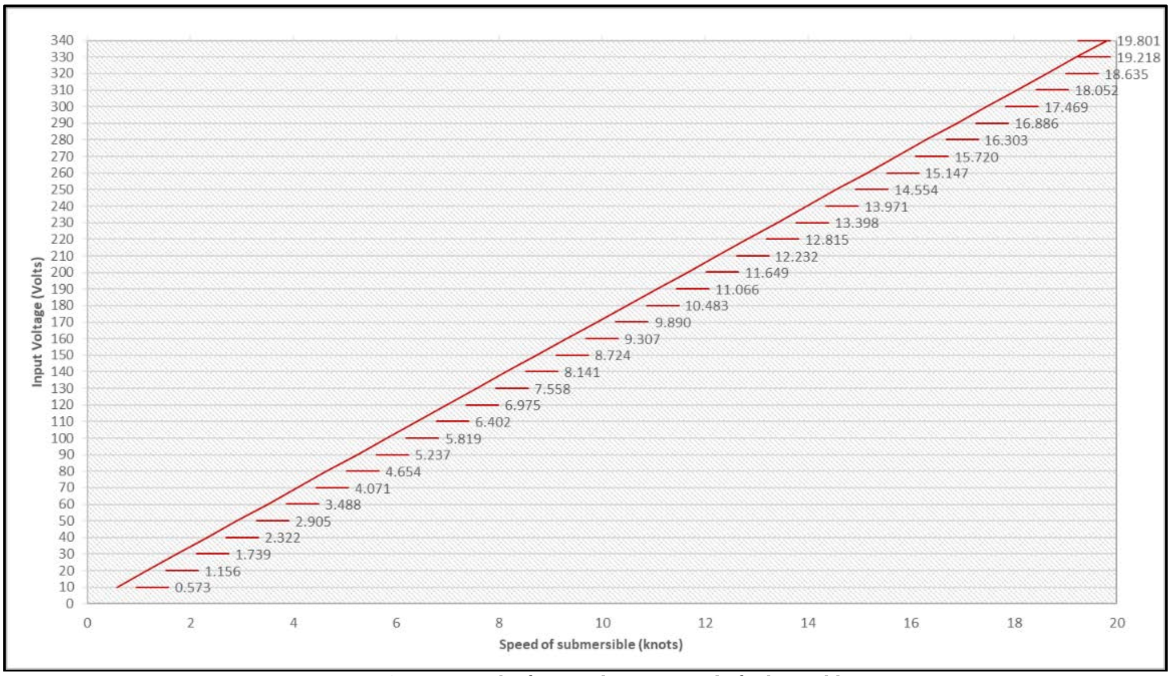

Figure 5*Graph ofinput voltage vs speed of submersible*

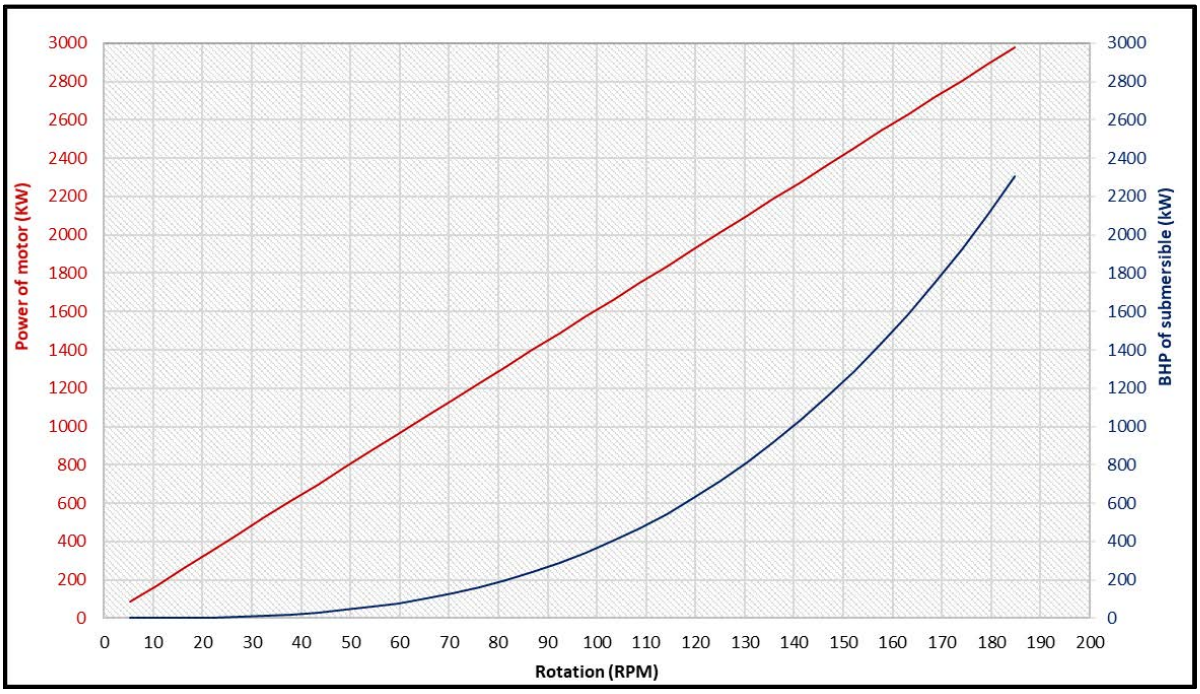

Figure 6*Graph of speed power performance using ohmformer*

F. Analysis of Graph without ohmformer

Figure 7 is graph showing the relationship between state of charge / SoC battery with speed of submersible. That graph is based on Table 5. Speed of submersible is directly proportional to input voltage. The decrease of state of charge / SoC battery will be followed the decrease of speed.

Figure 8 is graph showing speed power performance prediction of design without using ohmformer. That graph is based on Table 9. Power of submersible (BHP) is related with power of motor.

Figure 9 is graph showing in the relationship between state of charge / SoC battery with drop voltage. That graph is based on Table 3

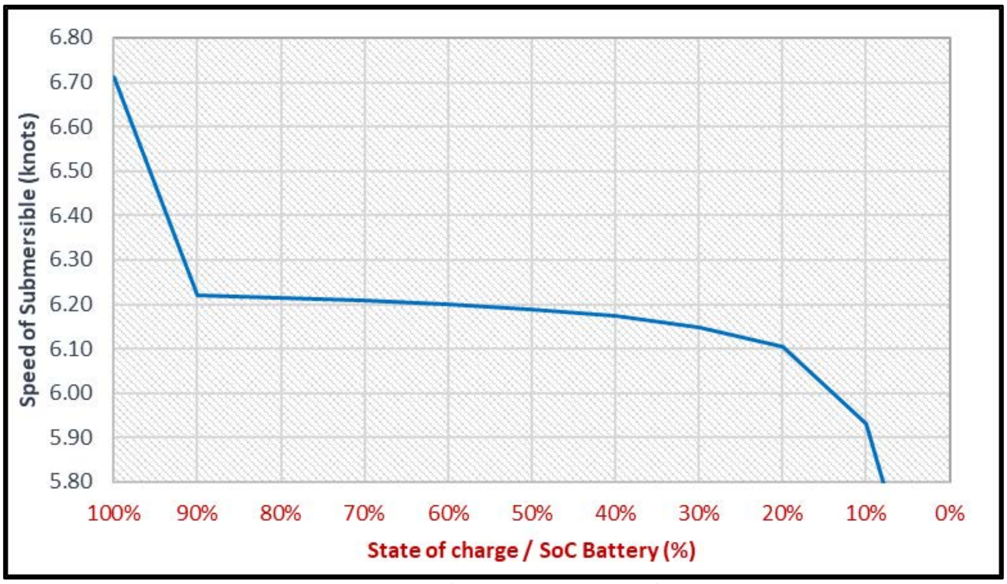

Figure 7*Graph of SoC battery vs speed of submersible*

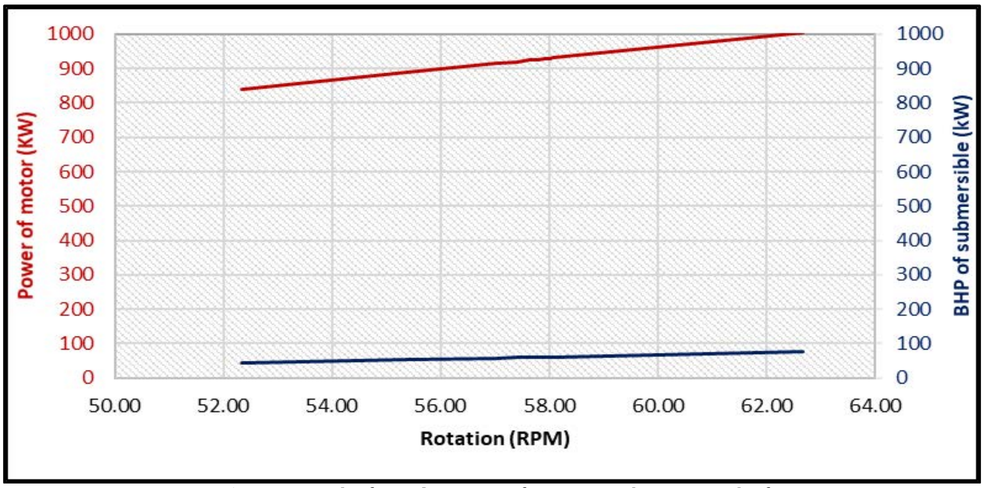

Figure 8*Graph of speed power performance without using ohmformer*

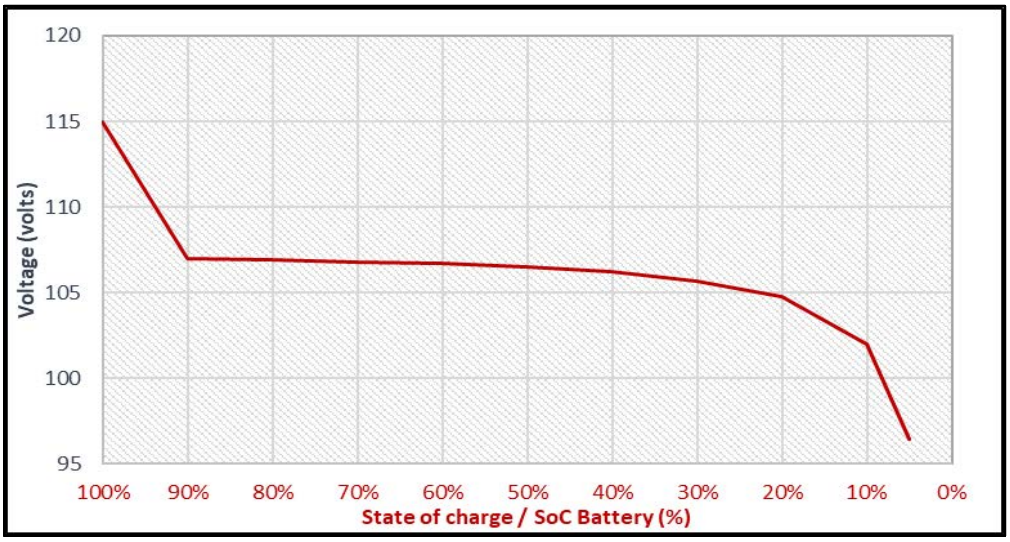

Figure 9*Graph of SoC battery vs drop voltage of battery*

IV. CONCLUSION

Conclusion that obtained from simulation, calculation and analysis this thesis are as follows:

1. Characteristic of design using ohmformer:
   a. Torque required for submersible is 100,2804 kNm
   b. Design using ohmformer can be used at speed of silent run, sailing run and quick run. Because of speed that be produced between 0.573 – 19.800 knots at 10 – 340 volts.
   c. Power of submersible that be produced between 0,056 – 2306 kW at 10 – 340 volts.
   d. Maximum efficiency at 92,39 % rpm and 77,41 % BHP.
2. Characteristic of design wihout using ohmformer:
   a. Design without using ohmformer can be used at speed of silent run. Because of speed that be produced between 5.605 - 6.711 knots at 115 volts.
   b. Power of submersible that be produced between 45.1054 – 77.4453 kW at 115 volts.
   c. Maximum efficiency at 31,33 % rpm and 7,71 % BHP.

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