Norges teknisk-naturvitenskapelige universitet **NTNU** **INSTITUTT FOR MARIN TEKNIKK**	**TMR4290 Marine electric power and propulsion systems**	
	Issued date / time:	Due date / time: **See Its learning**
Faggruppe: Marine systemer Adresse: Marinteknisk senter, Tyholt Telefon: 73595501 Telefax: 73595697	Project type: **Individual**	Weight on final grade: **15%**
PROJECT 1 – Matlab calculations for a marine power plant		

1 System description

Consider a small power plant having the following single line diagram:

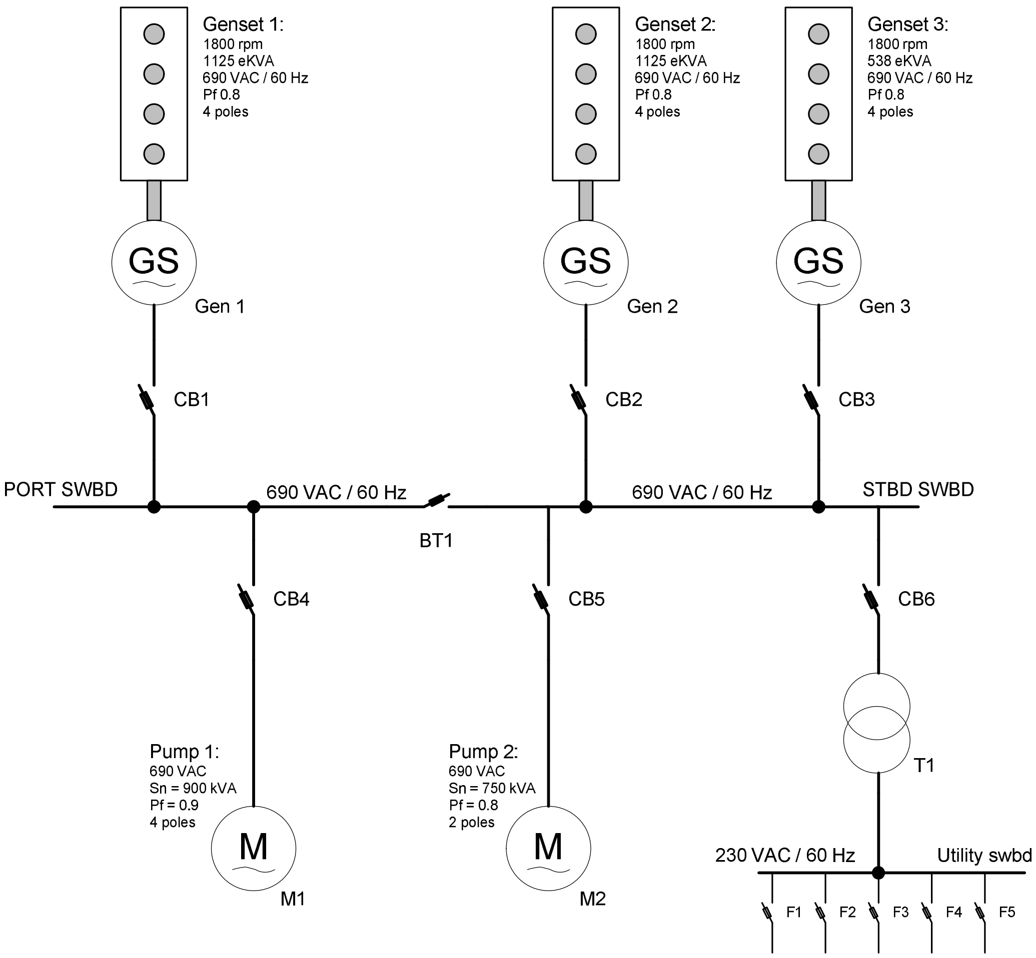

Figure 1: Single line diagram for power plant.

The power plant is a 3-phase system with neutral wire, a so-called TN-S system with nominally 690 Vac Line-to-Line.

1.1 Equipment parameters

Table 1: Parameters for the electric components.

Genset 1 **Genset 2**	S_N = 1125 kVA (rated apparent loading) Power factor = 0.8 (typical, at rated loading) Ra1 = 0.0001 Ω Xs1 = 0.5095 Ω 1800 rpm 4 poles 690 VAC Line-to-Line
Genset 3	S_N = 538 kVA (rated apparent loading) Power factor = 0.8 (typical, at rated loading) Ra3 = 0.0004 Ω Xs3 = 1.0665 Ω 1800 rpm 4 poles 690 VAC Line-to-Line
Induction motor M1	Slip s = 2.0% Rsm = 0.4169 Ω Xsm = 0.2429 Ω Xm = 0.0065 Ω Rc = 290.0 Ω R2 = 0.023 Ω X2 = 0.264 Ω
Induction motor M2	Slip s = 2.5% Rsm = 0.5854 Ω Xsm = 0.7255 Ω Xm = 0.0140 Ω Rc = 325.0 Ω R2 = 0.026 Ω X2 = 0.295 Ω
Transformer T1	Turns ratio N = 0.57735. Connected Ynyn
Utility load	Z_{La} = 0.2984 + j0.2250 Ω Z_{Lb} = 0.2984 + j0.2250 Ω Z_{Lc} = 0.2984 + j0.2250 Ω

The phase sequence is positive (abc) by construction of the plant.

1.2 Project objective

You shall develop several program functions and an overall computer program in Matlab that calculates the active and reactive power sharing between the generators, and other relevant electric parameters, for the small marine power plant above. The analysis shall be based on methods that now are familiar to us.

To write an m-script in Matlab as a function, type “help script” and “help function” in the Matlab command window.

2 Loads

2.1 Induction motor loads

An induction motor can be represented by the per-phase equivalent circuit of Figure 2, where *s* is the slip.

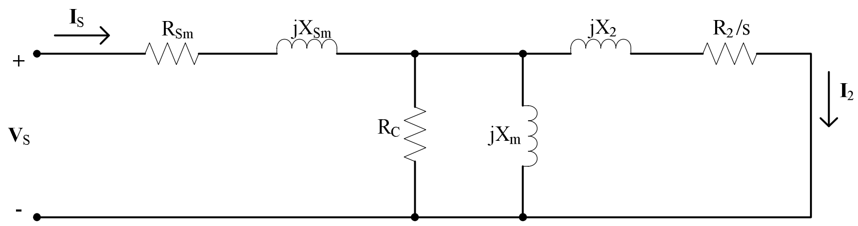

Figure 2: Equivalent per-phase circuit for induction motor.

This motor circuit can be represented by a resulting per-phase impedance Z_M for each induction motor M_1 and M_2, according to Figure 3:

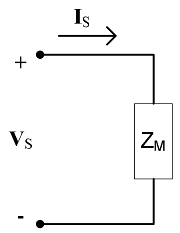

Figure 3: Resulting per-phase impedance of induction motor.

The induction motors are Wye-connected, where each of the three phase impedances are equal to the resulting per-phase impedance of Figure 3.

2.2 Utility loads

The transformer is Wye-Wye connected (Ynyn) with turns ratio $N = 1/\sqrt{3}$ such that the secondary phase voltage (line-to-neutral) becomes 230 VAC in the nominal case.

The per-phase transformer and utility load can be represented by the "Impedance Reflection 1: How does the sorce see the load?" of Lecture 5 on Transformers. We assume initially that the utility load is balanced (even if this is likely not to be true) and Wye-connected.

2.3 MATLAB SCRIPT 1: Resulting load impedances

Note that the status of the bus-tie breaker will separate the power system in one common or two separated systems.

Make a Matlab m-file function that calculates the **resulting per-phase load impedances** based on the following specifications:

- **Inputs:**
    - The closed/open status [1/0] of the bus-tie breaker BT1, and
    - the closed/open statuses [1/0] of the load feeders CB4, CB5, CB6.
- **Parameters:** See Table 1.

- **Outputs:** Resulting load impedance vectors for the three phases $[Z_{L,a}\ Z_{L,b}\ Z_{L,c}]^T$, for:
  - port bus and starboard bus if BT1 = 0, or
  - the connected bus if BT1 = 1.

Note, if a bus has no connected load, then the resulting load impedance is clearly infinite for that bus.

3 Generators

3.1 Generator equivalent circuits

The synchronous generators can be represented by the following per-phase equivalent circuit:

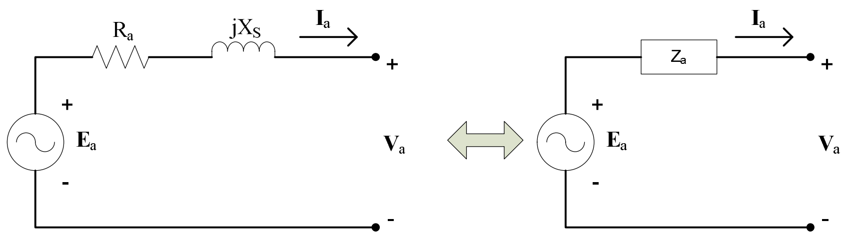

Figure 4: Equivalent per-phase circuit for synchronous generator (here a-phase).

In Figure 4, X_s is the synchronous reactance and R_a is the internal resistance of the stator for phase a. and the internal voltage $\boldsymbol{E}_a$ is the induced electro-motive force (emf), expressed as an rms- phasor as:

$$\boldsymbol{E}_a = \tilde{E}\angle\theta$$

where $\tilde{E}$ is the internal rms voltage, and θ is the internal voltage phase angle for the generator.

If for instance three generators are connected in parallel to the same bus, then this is modeled as a circuit as shown in

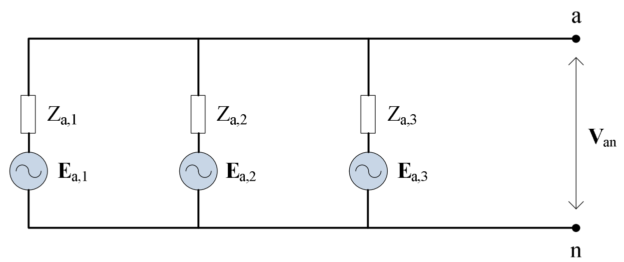

Figure 5: Per-phase diagram showing three generators connected in parallel to supply a power bus.

Such a circuit can again be simplified by Thévenin's theorem, resulting in a single voltage source and series resistance. This is your next task. Hint: Consider source transformations between Thévenin and Norton sub-circuits.

3.2 MATLAB SCRIPT 2: Thévenin equivalent supply circuit

Note that the status of the bus-tie breaker will separate the power system in one common or two separated systems.

A single Thévenin equivalent circuit can be used to represent one or several parallel connected generators.

Make a Matlab m-file function that calculates the **per-phase Thévenin equivalent supply circuit** of the connected generators based on the following specifications:

- **Inputs:**
  - The closed/open status [1/0] of the bus-tie breaker BT1,
  - the closed/open statuses [1/0] of the generator incomers CB1, CB2, CB3,
  - the internal rms voltages $\tilde{E}_1, \tilde{E}_2, \tilde{E}_3$ and phase angles $\theta_1, \theta_2, \theta_3$ for each generator.
- **Parameters:** See Table 1.
- **Outputs:** Resulting Thévenin voltages $\left[V_{T,a}\ V_{T,b}\ V_{T,c}\right]^T$ and Thévenin impedance Z_T for the three phases, for:
  - port bus and starboard bus if BT1 = 0, or
  - the connected bus if BT1 = 1.

Note, if a bus has no generators connected, then the Thévenin voltage is clearly zero for that bus.

4 Matlab programs

4.1 Resulting circuit diagram

When the consumers on a bus are represented by a single resulting 3-phase load impedance, and the generators are represented by a single 3-phase Thévenin equivalent, then the resulting 3-phase circuit diagram for the power plant becomes as shown in Figure 6.

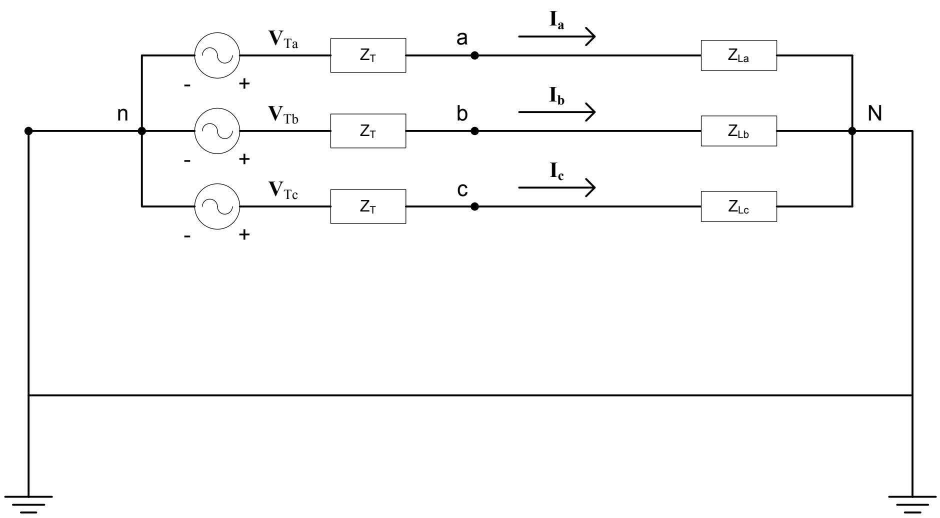

Figure 6: Resulting 3-phase equivalent circuit for the power plant.

4.2 MATLAB SCRIPT 3: Node voltage analysis

Set up the equations for a Node-Voltage analysis for nodes **a**, **b**, and **c**.

Make a Matlab m-file function that applies the two Matlab scripts above (Matlab scripts 1 and 2) and calculates the node voltages $[V_{an}\ V_{bn}\ V_{cn}]^T$ on each bus based on breaker statuses and internal voltages as needed by the two scripts.

In your computer program, the equations from the Node-Voltage analysis can be implemented as a linear set of equations $\boldsymbol{Ax} = \boldsymbol{b}$.

4.3 MATLAB SCRIPT 4: Electric parameters for loads

Make a Matlab m-file function that takes the corresponding bus node voltages $[V_{an}\ V_{bn}\ V_{cn}]^T$ and breaker statuses for each consumer (M1, M2, and T1) as inputs and calculates the following electrical parameters:

1. The motor currents I_{M1}, I_{M2} for each phase, and the current I_n in the neutral wire.
2. The transformer currents I_{T1} for each phase, and the current I_n in the neutral wire.
3. The total active and reactive loads for the induction motors and the transformer load; $[P_{M1}, Q_{M1}]$, $[P_{M2}, Q_{M2}]$, and $[P_{M3}, Q_{M3}]$.
4. Power factors for the loads; $\cos\varphi_{M1}$, $\cos\varphi_{M2}$, and $\cos\varphi_{T1}$.

4.4 MATLAB SCRIPT 5: Electric parameters for generators

Make a Matlab m-file function that takes the corresponding bus node voltages $[V_{an}\ V_{bn}\ V_{cn}]^T$, generator internal voltages, and breaker statuses for each generator as inputs and calculates the following electrical parameters:

1. The generator currents I_{G1}, I_{G2}, I_{G3} for each phase, and the current I_n in the neutral wire.
2. The active power delivered to the network by each generator; P_{G1}, P_{G2}, P_{G3} in kW and in %-loading of their rated values $P_N = S_N \cos\varphi_N$.
3. The reactive power for each generator; Q_1, Q_2, Q_3, in kVAr and in %-loading of their rated values $Q_N = S_N \sin\varphi_N$.

4.5 MATLAB SCRIPT 6: Overall program

Make a Matlab m-file program that takes as inputs the breaker statuses and generator internal voltages, runs the five scripts above in correct order, and displays the following parameters:

1. The bus phase voltages $[V_{an}\ V_{bn}\ V_{cn}]^T$ and line-to-line voltages $[V_{ab}\ V_{bc}\ V_{ca}]^T$ in rms values.
2. The parameters calculated by Matlab script 4.
3. The parameters calculated by Matlab script 5.
4. The total consumed and supplied complex power $S_{consumed} = [P_c\ Q_c]^T$ and $S_{supplied} = [P_s\ Q_s]^T$ for each bus, based on status of bus-tie breaker.

5 Simulation cases

Execute the following simulation cases and document the results in the final report:

5.1 Case 1: All running – all breakers closed.

1. Let $\tilde{E}_1 = \tilde{E}_2 = \tilde{E}_3 = 650\,V$ and $\theta_1 = \theta_2 = \theta_3 = 15°$.

   a. Run your program and verify that:
      i. Bus load impedance per phase: 0.199557 + j0.154257 Ohm.
      ii. Resulting Thévenin impedance per phase: 0.000047448 + j0.20563169 Ohm.
      iii. Resulting Thévenin voltage a- phase is 650 V rms, angle 15 deg.

   b. Tabulate the values of all signals listed in 1-4 for Matlab script 6.

   c. Verify that the total consumed complex power match the supplied complex power for the common connected bus, and is equal to 1.493479 +j1.154457 MVA.

   d. Verify that the active power is approximately equal in %-loading for the 3 gensets.

   e. Verify that the reactive power is approximately equal in %-loading for the 3 gensets.

   f. Verify that the generator currents sum to zero, i.e. no current in neutral wire.

2. Let $\tilde{E}_1 = \tilde{E}_2 = \tilde{E}_3 = 650\,V$ and $\theta_1 = 14°$, $\theta_2 = 15°$, and $\theta_3 = 16.5°$.

   a. Run your program, verify that the resulting a-phase Thévenin voltage changes to 649.92 V rms angle 14.89 deg.

   b. Tabulate the values of the active and reactive power delivered to the network by each generator in %-loading of their rated values.

   c. Did this difference in phase angles mainly affect sharing of active or reactive power between the gensets? Answer qualitatively.

3. Let $\tilde{E}_1 = 640\,V$, $\tilde{E}_2 = 650\,V$, and $\tilde{E}_3 = 675\,V$ and $\theta_1 = \theta_2 = \theta_3 = 15°$.

   a. Run your program, verify that the resulting a-phase Thévenin voltage changes to 650.78 V rms angle 15.00 deg.

   b. Tabulate the values of the active and reactive power delivered to the network by each generator in %-loading of their rated values.

   c. Did this difference in internal rms voltages mainly affect sharing of active or reactive power between the gensets? Answer qualitatively.

5.2 Case 2: 2-split system, Gen2 disconnected.

Let BT1 = 0, CB2 = 0, and CB5 = 0 (M2 disconnected), and set all other breakers closed.

1. Let $\tilde{E}_1 = 710\,V$, $\tilde{E}_2 = 0\,V$, $\tilde{E}_3 = 696\,V$ and $\theta_1 = \theta_2 = \theta_3 = 20°$.

    a. Run your program and verify that the line-to-line voltage V_{ab} is 690.18 Vrms, angle 24.23 deg on the starboard bus and 689.95 Vrms, angle 19.68 deg on the port bus.

    b. Tabulate the values of the active and reactive power delivered to the network by each genset in %-loading of their rated values.

2. Close the bus-tie breaker (BT=1), let $\tilde{E}_1 = \tilde{E}_3 = 705\,V$, $\tilde{E}_2 = 0\,V$, and $\theta_1 = \theta_2 = \theta_3 = 20°$.

    a. Run your program and report the bus line-to-line voltage V_{ab}.

    b. Tabulate the values of the active and reactive power delivered to the network by each generator in %-loading of their rated values.

    c. How did the generator loading change for Gen1 and Gen3 as compared to Case 2.1(b)? Answer qualitatively.

6 Report

The project shall be documented by a final report, maximum 6 pages + appendices with source code, written individually be each student.

The report should as minimum document:

- derivations to develop the necessary algorithms,
- the results of the calculations for the two simulation cases, and
- the resulting Matlab code for each script in the appendix.

Try to tabulate the numerical answers in two tables – one for each case – and provide qualitative assessments below.

Note that all voltages shall be presented in RMS values and all angles shall be presented in DEGREES.

The report shall be organized in a rational manner to give a clear exposition of derivations and results. The text should be brief and to the point, with a clear language, and written in English (preferably US). Any material taken from other sources shall be clearly identified and properly acknowledged. Any plagiarism is taken very seriously by the university, and any such practice will always have consequences.

The report shall be turned in electronically as a PDF on *It's Learning*.