9.TRANSFORMERS:

Transformers operate only at A.C. They do not change the frequency, they change the current and voltage values. They are static and operates according to the electromagnetic induction principle.

9.1 The operation and structure of the transformer:

Structure: Transformers are composed of two parts.

1- Core (magnetic part)

2- Windings; primary (Input), Secondary (Output) windings.

Core: It is the magnetic part of the transformer. They are fabricated by using 0,30 - 0,50 mm thick silycon and metal sheets of which one side is insulated in order to prevent eddy and hystheresis losses. It is tried to make the magnetic resistance of the core as small as possible. The core types used in transformers are;

1. Standard type
2. Mantel type
3. Distributed type

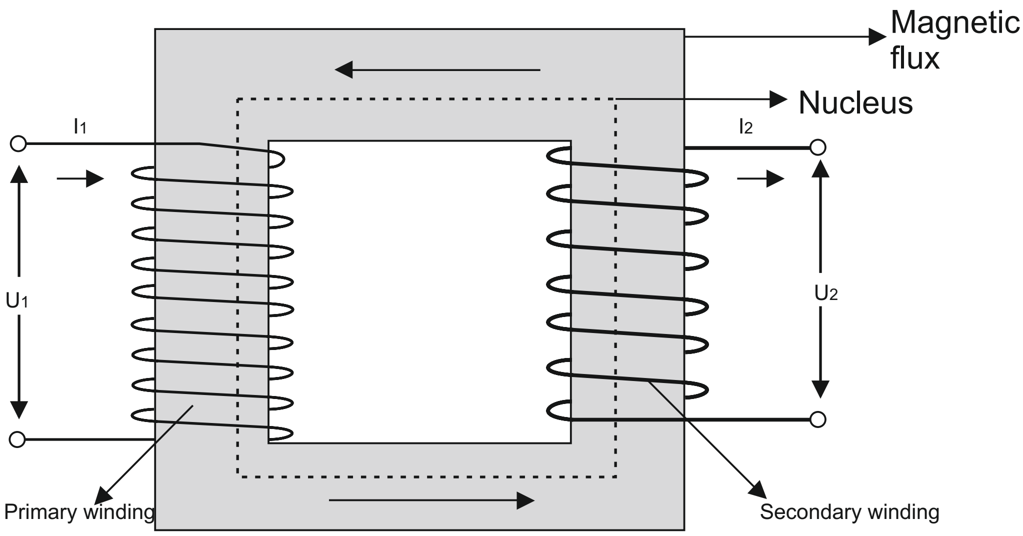


Figure- 9.1: Symbolic view of the transformer

Windings: There are 2 windings in the transformers. These are Primary and Secondary windings. The primary winding is the winding that the voltage is applied. It can be also called as input winding. In down-transformers, they are thin and high number of turn in up transformers they are thick and low number of turns. Secondary is the winding that the voltage is taken. The load is connected to that winding. In down-transformers, they are thick and low number of turns in up transformers they are thin and high number of turns.

OPERATION:

When AC voltage is applied to the primary windings of the transformer, an AC current passes through the primary windings even any load is not connected to the secondary winding. That current creates a varying magnetic fields. That magnetic field completes its circuit through the core and secondary windings. Due to that magnetic field a voltage with same frequency is induced. The induced voltage is proportional to the number of turns. As a result the voltage applied to the primary winding causes a voltage with the same frequency to be induced in the secondary winding due to electromagnetic induction.

9.2: Classification of the transformers according to voltage

If a transformer increases the voltage it is called up-transformer, if it decreases the voltage it is called down-transformer.According to voltage they are classified as;

0-1 kv Low voltage transformer
1-35 kv Mid voltage transformer
35-110 kv high voltage transformer
110-400 kv very high voltage transformer

9.3 Classification of Transformers

Transformers are classified according to their usage and fabrication. These are:

1. Core type
2. Establishment place
3. Cooling
4. Usage
5. Number of phases
6. Operation principle
7. Winding form and type

9.4 Induced EMF transformation ratio of the transformer

A voltage is induced through a coil placed in a varying magnetic field. The magnitude of that induced voltage (EMF) depends on frequency of the applied voltage (f), magnetic flux ($Ø_m$) and the number of turns (N).The equation is;

$$E = 4{,}44.f.Ø_m.N.10^{-8} \text{ Volt}$$
$$U = E_1 = E_p \text{ Primary input voltage}$$
$$E_1 = 4{,}44.f.Ø_m.N_1.10^{-8} \text{ Volt}$$
$$U_2 = E_2 = E_s \text{ Secondary output voltage}$$
$$E_2 = 4{,}44.f.Ø_m.N_2.10^{-8} \text{ Volt}$$

Induced voltage for each turn is;

$$U_s = \frac{U_1}{N_1} \text{ or } U_s = \frac{U_2}{N_2}$$

Transformers are the most efficient electrical machines if we omit the cupper and iron losses.

$$\eta = \frac{P_1}{P_2}$$

Primary power (P_1) Secondary power (P_2)

$$P_1 = U_1.I_1.Cos\varphi$$
$$P_2 = U_2.I_2.Cos\varphi$$
$$U_1.I_1.Cos\varphi = U_2.I_2.Cos\varphi$$

$$\eta = \frac{U_1.I_1.\cos\phi}{U_2.I_2.\cos\phi} = \frac{U_1.I_1}{U_2.I_2}$$

The voltage induced in the primary and secondary is proportional to number of turns.

$$Us = \frac{U1}{N1} = \frac{U2}{N2} \rightarrow U1.N2=U2.N1 \rightarrow U1 = \frac{N1.U2}{N2}$$

$$\frac{U_1}{U_2} = \frac{N_1}{N_2}$$

That relation between voltage-current and the number of turns is called transformation ratio or transformation factor. Transformation ratio is shown by a or k.

$$a(k) = \frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

$I_1.N_1 = I_2.N_2$ That equation is called ampere-winding.

9.5 Losses and efficiency in transformers

The losses of the transformers are only cupper and core losses.

Core Loss: It is due to eddy current and hystheresis losses and it is constant for all operation modes and loads. These losses can be found by applying no-load test to the transformer. Eddy current losses can be prevented by fabricating cores using metal sheets. The hystheresis losses can be prevented by adding silicone to the iron.

Cupper Losses: They are the losses due to the currents passing through the primary and secondary windings. They are the results of winding resistance. They increase with the increasing current passing through the winding. They are found by applying short circuit test to the transformer.

$$P_{cu} = P_{1cu} . P_{2cu}$$
$$P_{1cu} = I_1^2 . R_1$$
$$P_{2cu} = I_1^2 . R_2$$

The cupper loss of the transformer is approximately 3% - 4% of the transformer power. The efficiency of the transformer is the ration of the output power to the input power.

$$\eta = \frac{Po}{Pi} \text{ or } \frac{P_1}{P_2} \qquad Pl = P_{fe} + P_{cu}$$

$$\eta = \frac{Po}{Pi + Pl}$$

$$\% \eta = \frac{Po}{Pi} \cdot 100$$

9.6 The label of the transformer and connection symbols

The label and the connection symbols are standard for transformers. Generally in international standard symbols letters and numbers are used.

Turkish Standards:

The input of the transformer is shown by A-B or A1-B1 and the second group of windings are shown by A2-B2.

The output of the transformer is shown by lower case letters or numbers like a-b or a1-b1. The second group windings are denoted as a2-b2. The common terminal of the windings is shown by letter n.

For tri-phase transformers U-V-W is used for primary winding input, and X-Y-Z for the output. The small case of the same letters are used for secondary windings.

American Standards:

The primary windings are denoted as H1-H2 and the second group is H3-H4.The secondary windings are denoted as X1-X2 and the second group is X3-X4.

German Standards:

The primary windings are denoted as P1-P2 and the second group is P3-P4.The secondary windings are denoted as S1-S2 and the second group is S3-S4.

10. SINGLE PHASE TRANSFORMERS

They are the static electrical machines that transfer energy from one AC circuit to another AC circuit without changing the frequency. They are fabricated as single phase transformers. They are widely used in many applications.

10.1 . The operation and structure of single phase transformer

Single phase transformers are simple electrical machines and they are widely used in various applications. Magnetic core fabricated using siliconic metal sheets is wound in different shapes to form primary and secondary windings.

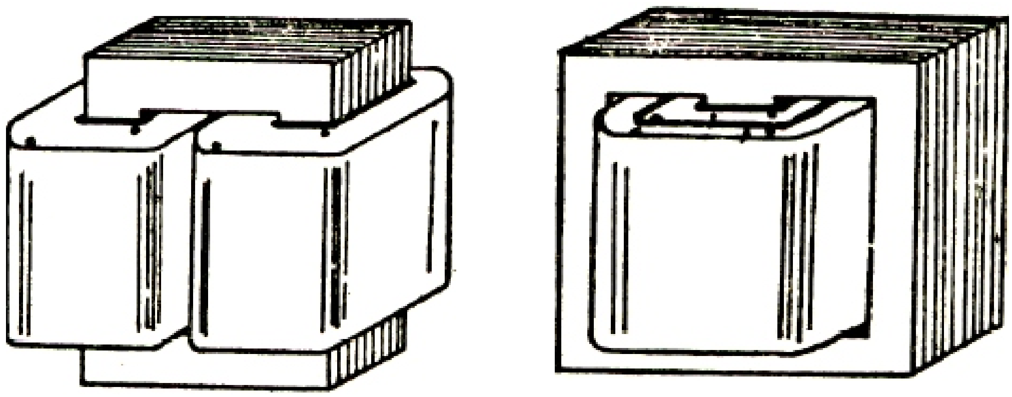


Figure 1: Simple single phase transformer

The first circuit that the voltage is applied is called the primary windings and the second circuit that the load is connected and the current is pulled is called the secondary winding. If the voltage in the secondary winding is less than the voltage in the primary winding the transformer is called down-transformer. If the voltage in the secondary winding is more than the voltage in the primary winding the transformer is called up-transformer. When an AC voltage is applied to the primary winding, the AC current creates a magnetic flux. That flux passes through the core and the secondary windings, so a voltage is induced in the secondary windings. The EMF value of the induced voltage is proportional to the magnetic flux, frequency of the AC voltage applied and number of turns ratio of the windings.

As we have explained above, the operation of the transformer depend on the transfer of the electrical energy by electromagnetic induction without changing the frequency.

10.2. The Induced IMF and the transformation ratio of the transformer

The IMF induced in the transformer depend on the magnetic flux created by the primary winding, the frequency of the AC voltage is applied, the structure of the magnetic core and the number of turns of the coils.

Therefore;

$E_1 = 4,44 \,.\, f \,.\, Ø_m \,.\, N_1 \,.\, 10^{-8}$ Volt.

The efficiency of the transformers are very high because they do not have any rotating part. The iron-cupper losses have very small values. If those losses are omitted, the powers at the primary and secondary windings are assumed to be equal.

$P_p = P_s$;

$E_1 \,.\, I_1 \,.\, \mathrm{Cos}\varphi = E_2 \,.\, I_2 \,.\, \mathrm{Cos}\varphi$

By the help of that equation;

$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = a$$

As it is understood from the equation, the voltages are directly proportional with the number of turns and inversely proportional to the current. That ratio is called the transformation ratio of the transformer. It is indicated by a or k.

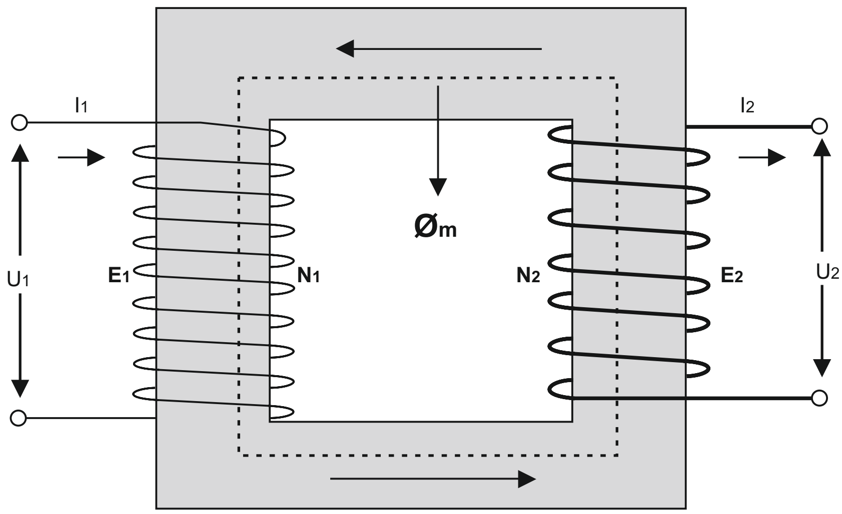


Figure- 10.2 Symbolic representation of a single phase transformer

10.3. The connection of the single phase transformer

The winding terminals of the single phase transformer is represented by letters and numbers. The rated values should be analyzed.

The primary windings are shown by A-B (A-B1, A2-B2 if the windings are distributed.) The common node is shown by N. The secondary windings are shown by a-b (a1-b1, a2-b2 if the windings are distributed.)The common node is shown by n.

The transformer should be used according to the rated values.

Experiment 19: THE NO-LOAD OPERATION OF THE SINGLE PHASE TRANSFORMER, FINDING ITS TURNS RATIO

Purpose: Analyzing no-load operation of the transformer, finding losses at no-load operation, finding turns ratio, getting experience about the subject.

Equipments:

- Experiment board with energy unit	Y-036/001
-A.C measurement unit	Y-036/005
-Energy analyzer	Y-036/004
-Single phase transformer	Y-036/027
-Jagged cable , cable with IEC plug	

Connection diagram for the experiment :

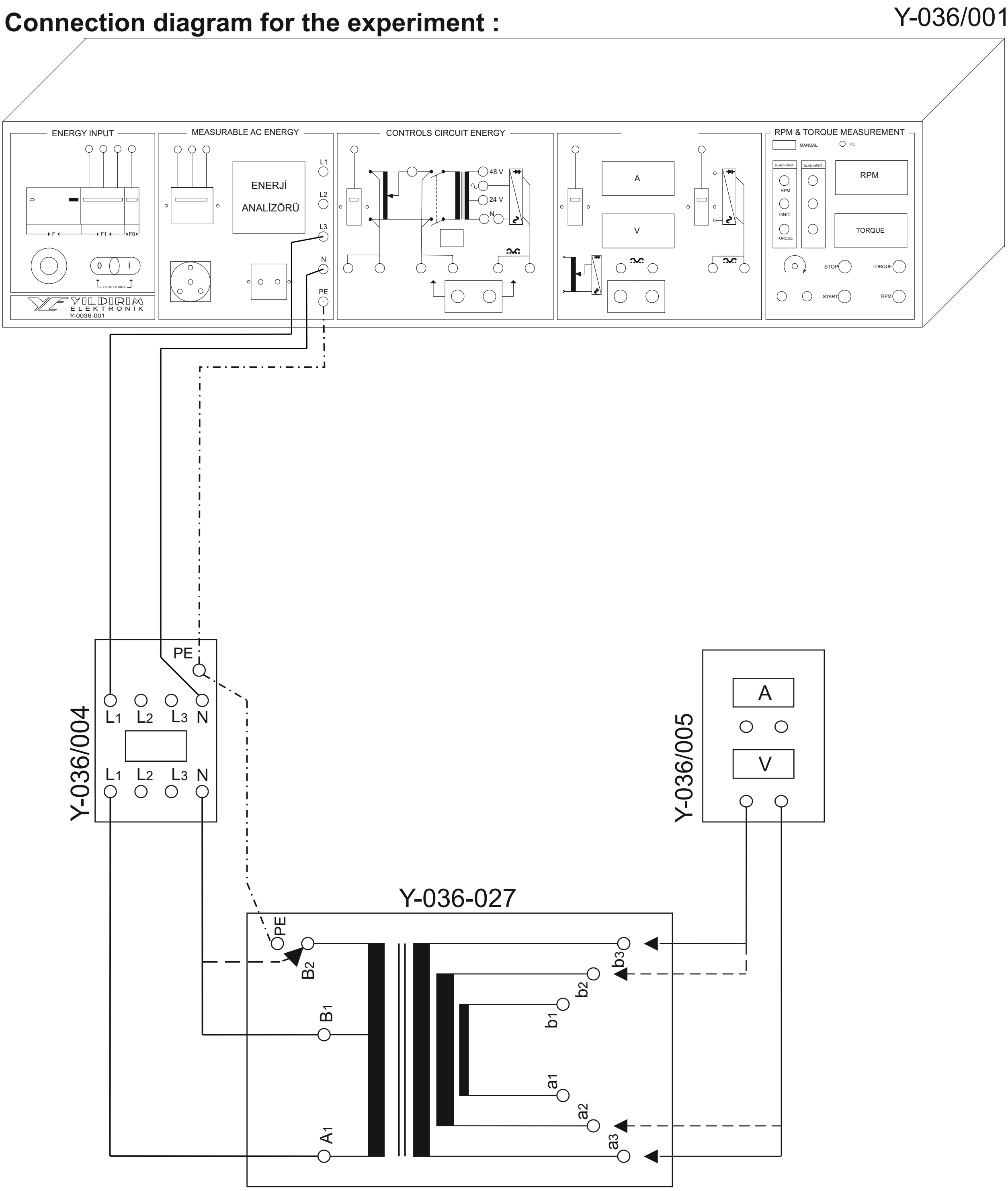


Figure 19.1 Connection diagram for no-load operation of the single phase transformer.

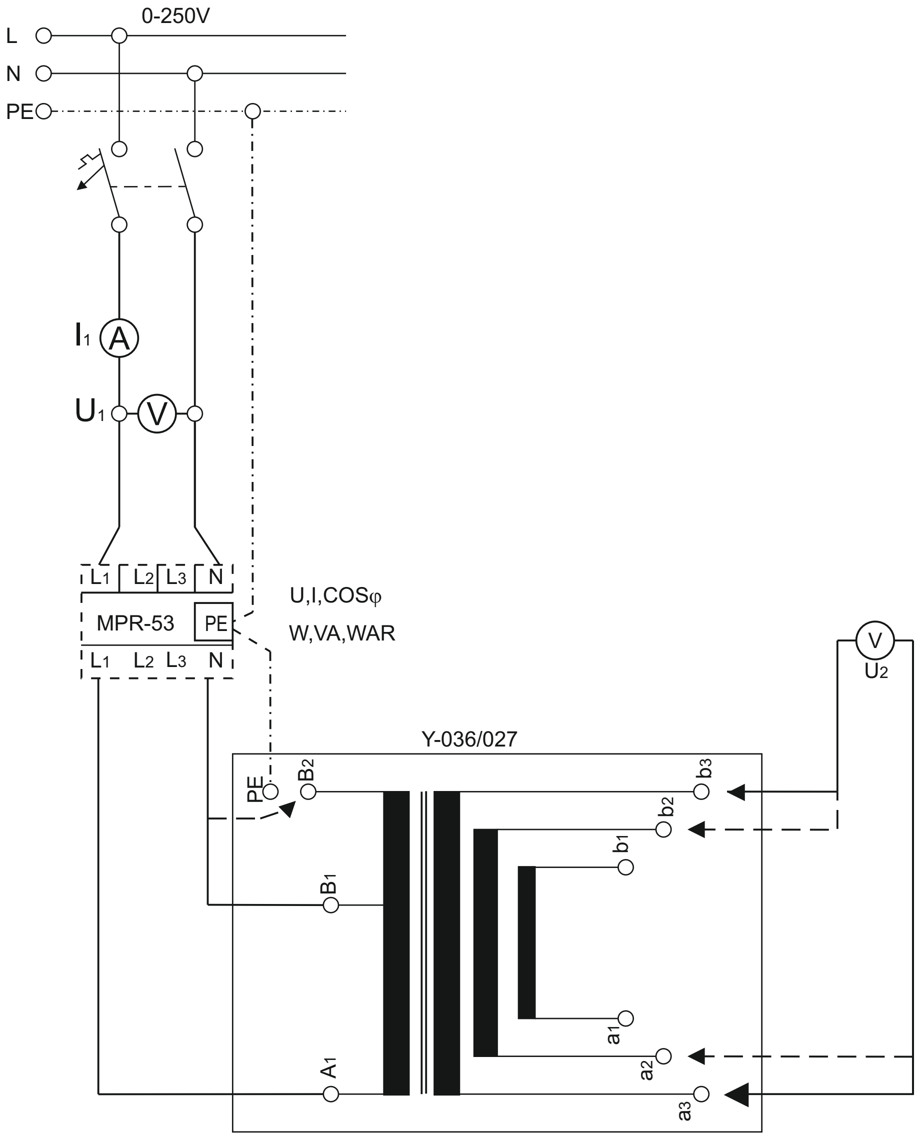


Figure 19.2 Connection diagram for no-load operation of the single phase transformer.

Procedure:

Note:∗Be careful about the rated values of the transformer. Two primary voltages are Indicated for the transformer. The higher one is the secondary and the lower one is the primary.The secondary voltage changes when the primary voltage changes.

** For no-load operation experiment, the values I, Cosφ and power may not be observed in the measurement unit since the current values are very low. For that case a multimeter with mA measuring capability can be used.

-Connect the circuit shown in figure 19.1-19.2

-Close the switch of the primary circuit and set the voltage of the primary winding to its rated value step by step starting from 0V.

-Take note of the values U, I, I2 and the values U, I, Cosφ, W, VA, VAR in the energy analyzer in each step.

-* If the Y-036/001 unit is not sufficient for the primary voltage, the Y-036/002 unit can be used.

-Turn of the energy and finish the experiment.

Values recorded in the experiment :

U_1	I_1	U_2	Energy Analyzer						Explanation
			U	I	cosφ	W	VA	VAR	

Evaluation :

Question 1: What is the power observed in the energy analyzer when the rated voltage(U1) is applied to the primary of the transformer, and there is no load at the secondary?
Question 2: Find the transformation ratio of the transformer using the values U1,U2 recorded in the experiment.
Question 3: Sketch the no-load operation graph of the transformer using the values U1, I2 and the values read in the energy analyzer.
Question 4: How can we find the number of turns of transformer?
Question 5: Explain the operation principle of the transformer.
Question 6: State your final observations about the experiment.

Experiment 20: MEASURING THE PRIMARY-SECONDARY CIRCUIT RESISTANCE OF THE SINGLE PHASE TRANSFORMER

Purpose: Getting experienced about measuring the DC values of the primary-secondary circuit resistances of the transformer.

Equipments: Experiment board with energy unit Y-036/001
-D.C measurement unit Y-036/006
Single phase transformer Y-036/027 or Y-036/028
-Jagged cable , cable with IEC plug
-Multimeter

Connection diagram for the experiment:

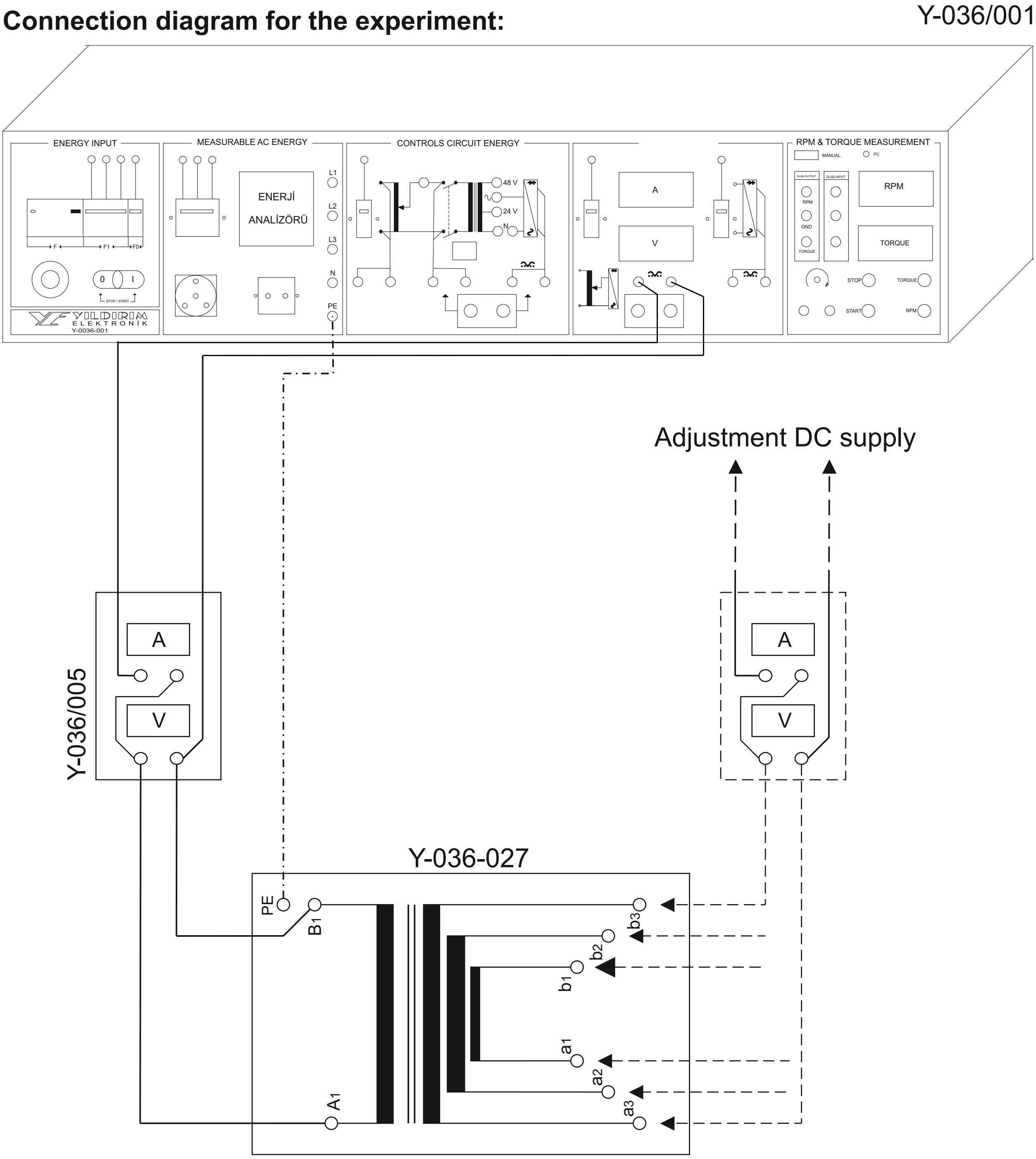
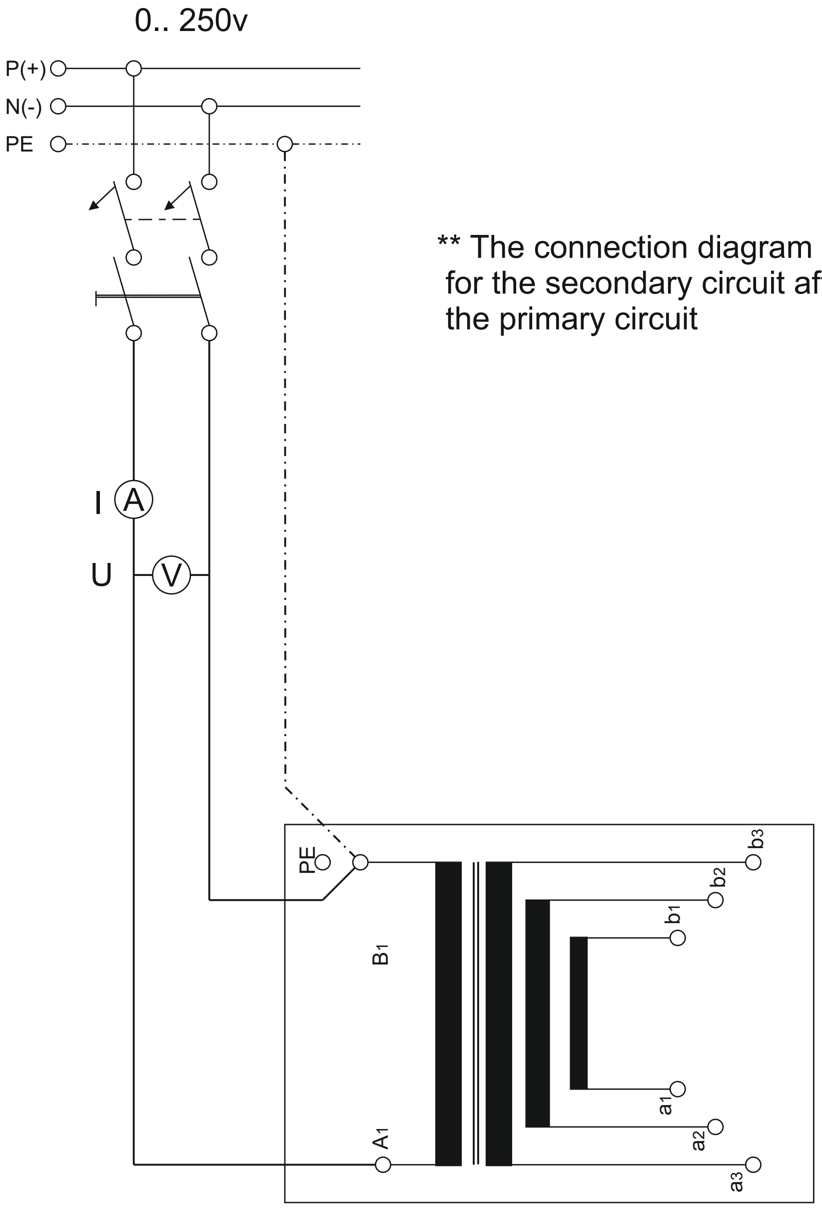


Figure 20.1Connection diagram for the experiment of measuring the primary-secondary circuit resistances
* The connection will be applied to primary and secondary one by one.



** The connection diagram will be used for the secondary circuit after using it for the primary circuit

Figure 20.1Connection diagram for the experiment of measuring the primary-secondary circuit resistances

Procedure:

Note:* Do not let current over the rated value pass through the primary-secondary windings. Do not operate it at rated current for a long time.

-Connect the circuit shown in the figure 20.1-20.2.
-Connect the variable DC power supply to the transformer. Adjust the supply voltage until the primary winding current takes its rated value step by step starting from zero.
-Observe and take note of U,I values in each step.
-Turn of the energy and finish the experiment.
-Repeat the same procedure on the secondary windings step by step.
-Observe and take note of U,I values in each step.
-Turn of the energy and finish the experiment.
-Measure the resistances of the primary and secondary circuits using ohmmeter in each step and record it.

Values recorded in the experiment :

PRIMARY				SECONDARY				Explanation
U_1	I_1	Found R	Measured R	U_2	I_2	Found R	Measured R	

Evaluation :

Question 1:Why did we use DC supply in the winding resistance measurement experiment? What would happen if we used AC supply?

Question 2: Why did we apply DC voltage considering the AC rated values? What would if we did not?

Question 3: Find the winding resistances of the transformer using the values U,I and the equation R=U/I?

Question 4: What happens if we apply AC voltage to the transformer? What is the reason of that change in the resistance value?

Question 5: Is there any diference between the value measured by ohmmeter and the value calculated by using the equation R=U/I? Explain the reason.

Question 6: State your final obsevations about the experiment.

6 –DC COMPOUND MACHINES:
6.1: STRUCTURE OF THE MACHINE:

DC compond machines can be used as series or shutn machines according to the connection of windings. Therefore compount machines are combination of series and shunt machines. These machines can be used as compound generators or motors. They have two excitation windings. One is connected in series with the armature and the other is connected in parallel with the armature.

Compound machines are composed of the two excitation windings, rotor with armature windings, brushes that supply current to the armature with the commutators. The excitation windings are connected as cumulative or deferential depending on the direction of the direction of the excitation field created. Compound machines may have series machine properties or shunt machine properties depending on the structure.

In compound machines series and shunt windings can be distributed. If the series windings are distributed, cumulative compound machines can be obtained. The windings can be connected as cumulative, differential or combination of both. The types and properties of compound machines are given below:

Reverse compound machines:

If the series windings of the compound machine are connected as to oppose the flux created by the shunt-connected windings, a reverse compound machine is obtained. The speed remains constant with the increasing load or it can be increase depending on the number of turns of the windings.

Undercompound machine:

They have mostly the properties of the shunt motor. The series winding is connected so as to aid the field of the shunt winding.

Normal compound machines:

That type of machines carry all the properties of shunt machines. The initial torque is very high and the speed highly depends on the load.

Overcompound machines:

That type of machines mostly carry the properties of the series machines. The following properties are observed in generator operation of cumulative compound machines.
a)Overcompound: They carry shunt generator properties.
b)Undercompound: They carry series generator properties.
c)Reverse compound: The field of the series windings oppose the field of the shunt windings. In that case, the machine carry the properties of the dominant winding.
d)Normal compound: The fields of both windings are in the same direction. They carry properties of both windings.

6.2 : MOTOR OPERATION PROPERTY:

Compound machines show the properties of shunt machines at no-load operation. That means machine is not broken down at no-load operation. In order the machine to be broken down, the two windings must be discarded or their fields must annihilate each other. Unlike series motors, their speed is not decreased by the increasing load. At low speeds they show the properties of series motors.

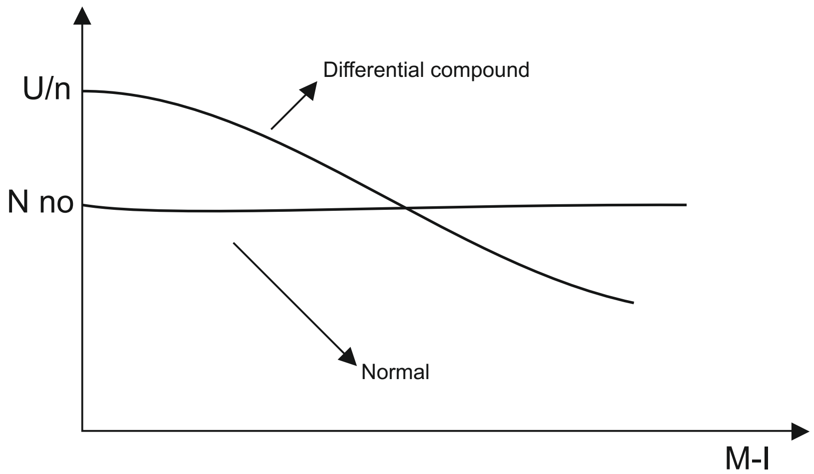


Figure- 6.1: The cumulative and normal compound motor loading curve

In motor operation of the cumulative compound machines, the property of the operation is determined by the direction of currents passing through the windings and the effect of fields on each other.
In normal compound case, the motor carry shunt motor properties.
In reverse compound case, the speed is constant while the load is being increased. Moreover, speed can be increased depending on the coil selected.
In overcompound case, the motor mostly carry series motor properties.
In undercompound case, the motor mostly carry shunt motor properties.

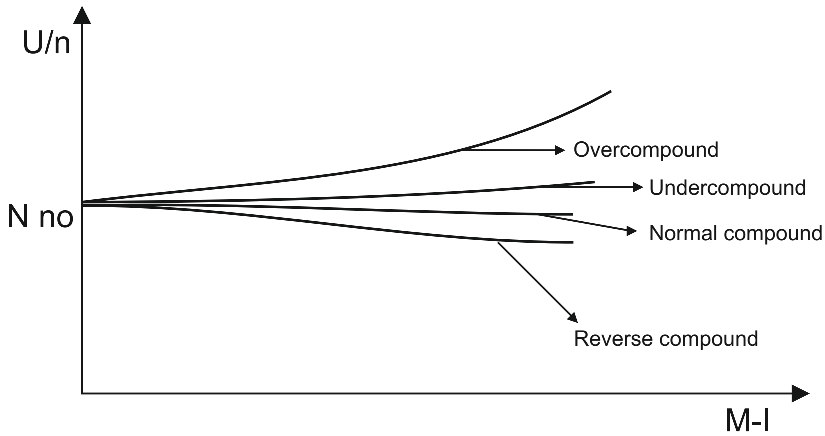


Figure- 6.2: The load curves of the cumulative compound motor for different cases

The cumulative compound motors can be operated at no-load like normal compound motors. But, discarding the two windings or opposite fields that cancel out each other damages the motor.

6.3: GENERATOR OPERATION PROPERTY

Compound generators carry properties of both the series and the shunt generators. They can operate as separately or self excited. They can be designed as cumulative compound or differential compound. Even the compound generator is overloaded by the network, they keep their voltage constant. The polarization do not change due to the shunt winding even the direction of the current in the windings is changed. They carry shunt generator property in overcompound case; series generator property in undercompound case.

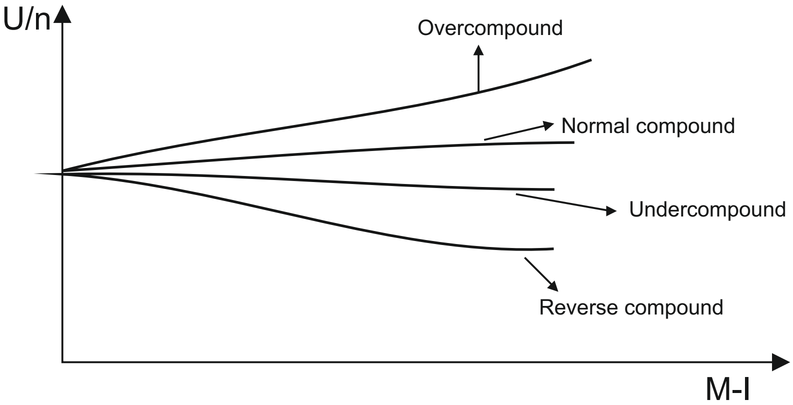


Figure- 6.3: The load curves of the cumulative compound motor for different cases

6.4 STARTING THE MACHINE

It is necessary to use starter rheostat in DC cumulative compound machines since they pull currents too higher than the rated value at starting.

Also it can be started by using a variable DC source. Likewise the case in the other DC machines phase controlled systems with thyristors can be used at starting in order to prevent the machine pull very high currents at starting.

6.5 MACHINE CONNECTIONS:

The terminals of the commutative compound machines are A1-A2 for armature windings, D1-D2 for excitation series windings, E1-E2 or F1-F2 for shunt windings. It is necessary to read the rated values of the machine before operating it. The rated current and voltage values must be considered.

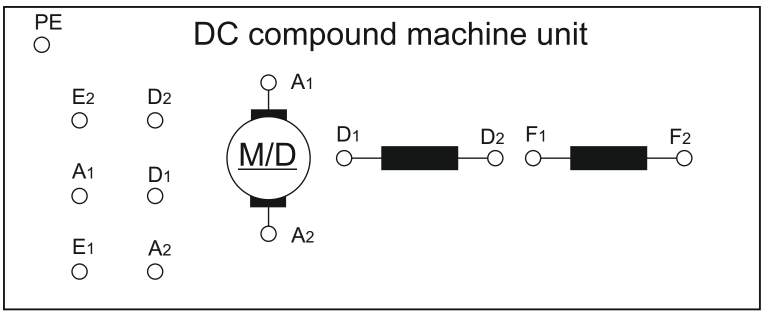


Figure- 6.4 DC compound machine unit

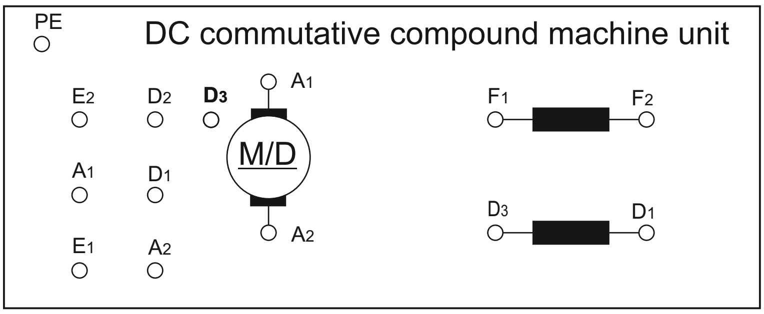


Figure- 6.5 DC commutative compound machine unit

Experiment 14: NO-LOAD OPERATION OF THE DC COMPOUND GENERATOR

Purpose: Operating the compound generator at no-load, analyzing the relation between the excitation current (Ie) and the generator voltage (U).

Equipments :

-Experiment board with energy unit Y-036/001
-Railed motor table Y-036/003
-D.C compound machine Y-036/022
-Three phase asynchronous motor Y-036/015
-Three phase asynchronous motor controller Y-036/026
-D.C measurement unit Y-036/006
-Excitation (Re) rheostat 100 Ω 500w Y-036/065
-Tachometer (speedometer)
-Jagged cable ,cable with IEC plug

Connection diagram for the experiment: Y-036/001

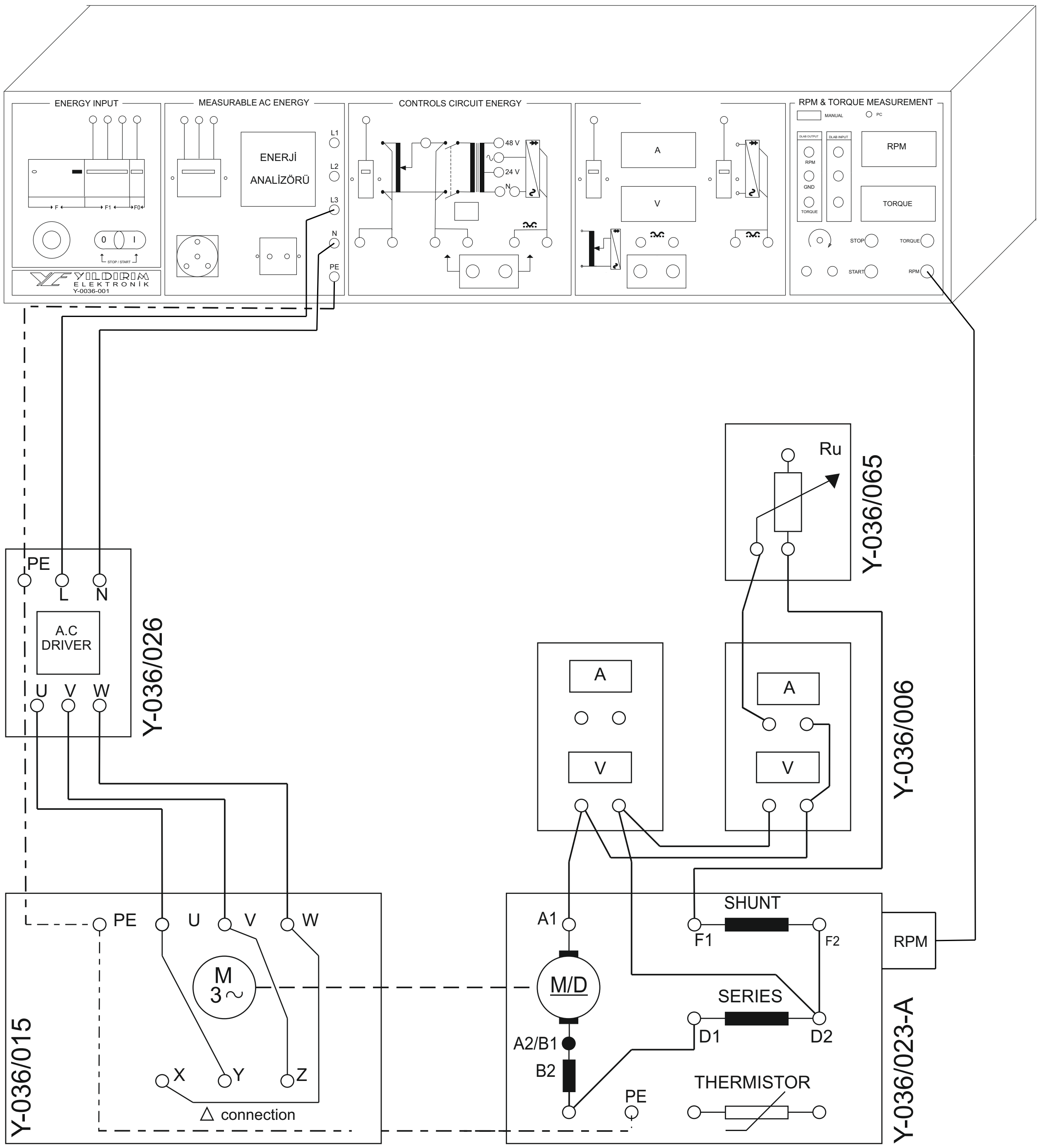


Figure 14.1:Connection diagram for no-load operation of the DC compound generator

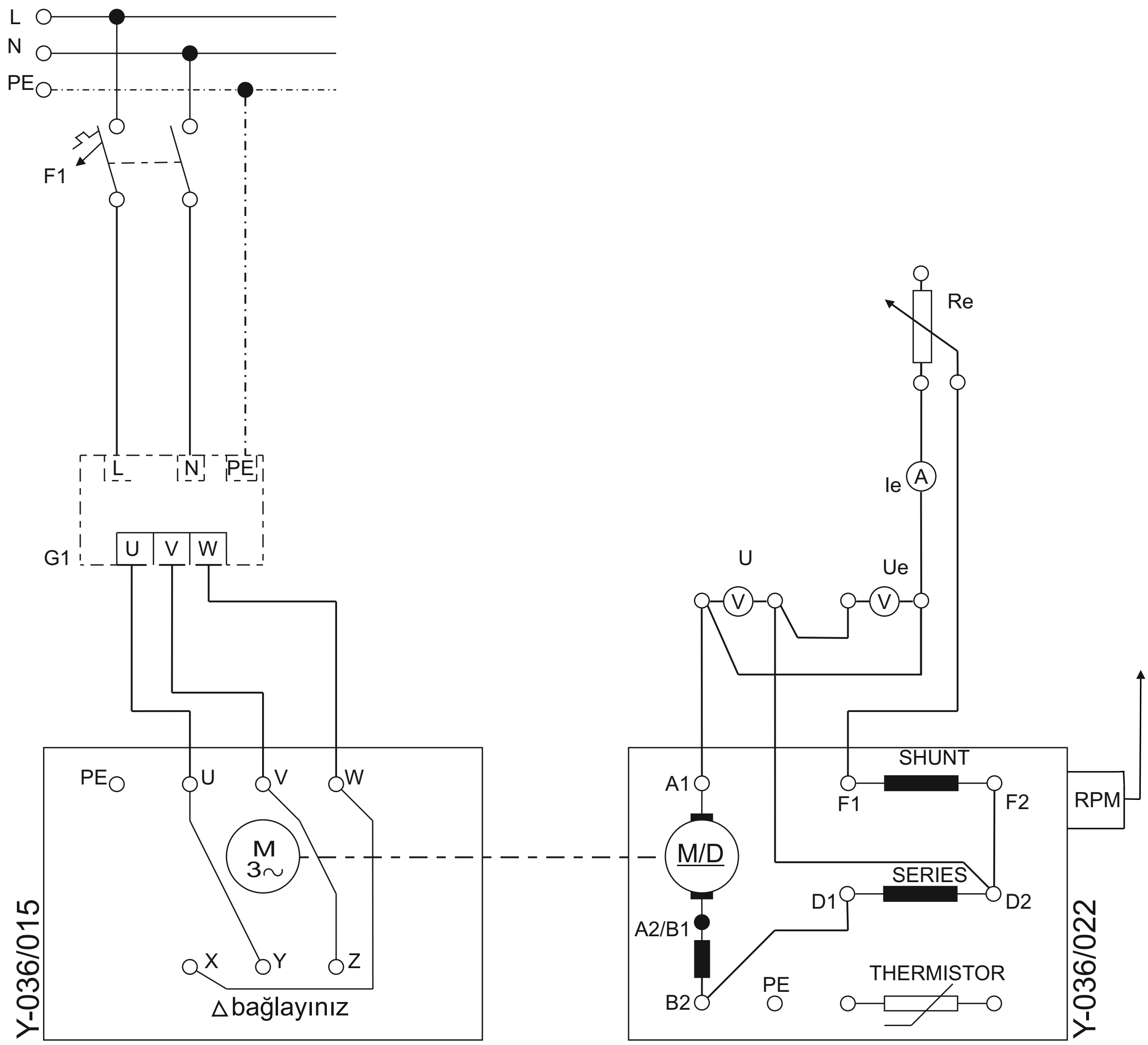


Figure 14.2:Connection diagram for no-load operation of the DC compound generator

Procedure:

Not:∗The DC compound machine includes the parallel machine properties. (Precaution about no-load operation!)

∗Be careful about the rated values of the AC-DC machines.

-Connect the circuit shown in figure 14.1 and 14.2.
-Set the speed of the DC compound machine to its rated value using the asynchronous motor and its controller. Take note of the values U and n while the excitation current (Ie) is zero.
-Decrease the excitation rheostat (Re) step by step and take note of the values U. Ue, Ie and n in each step.
-Set the output voltage of the DC compound generator to its rated value varying either the excitation current (Ie) or the speed (n).
-Decrease the excitation current (Ie) increasing the excitation resistance (Re) step by step until the exitation resistance takes its maximum value. Take note of the values U, Ue, Ie and n in each step.
-Turn of the energy and finish the experiment.

∗∗ Optional: Supply the shunt excitation windings with the rated voltage using a separate DC source. Repeat the experiment and analyze your observations.

Values recorded in the experiment:

n	U	Ue	Ie	Explanation

Evaluation:

Question 1: What is the voltage (U) read before the generator is excited? If it is zero explain the reason.
Question 2: Sketch the no-load using the values U and Ie recorded.
Question 3:Does the generator voltage increase withe the excitation current? Explian.
Question 4:What would happen if the series properties of the DC compound generator were as much as the shunt properties? Explain.
Question 5:Is there any voltage drop when the generator is operating at no-load? Explain the reason.
Question 6: State your final observations about the experiment.

Experiment 15:LOADED OPERATION OF THE DC COMPOUND GENERATOR

Purpose: Operating the compound generator at load, analyzing the relation between the load current (IL) and the generator voltage (U).

Equipments :

-Experiment board with energy unit	Y-036/001	-D.C compound machine	Y-036/022
-Railed motor table	Y-036/003	-D.C measurement unit	Y-036/006
-Three phase asynchronous motor controller	Y-036/026	-2 pole switch with fuse	Y-036/052
-Three phase asynchronous motor	Y-036/015	-Tri-phase lamp group	Y-036/055
-(Re) excitation rheostat 100 Ω 500w	Y-036/065	-Takametre, Jagged cable	
-(RL) load rheostat 50 Ω 1000w	Y-036/066	-cable with IEC plug	Y-036/001

Connection diagram for the experiment :

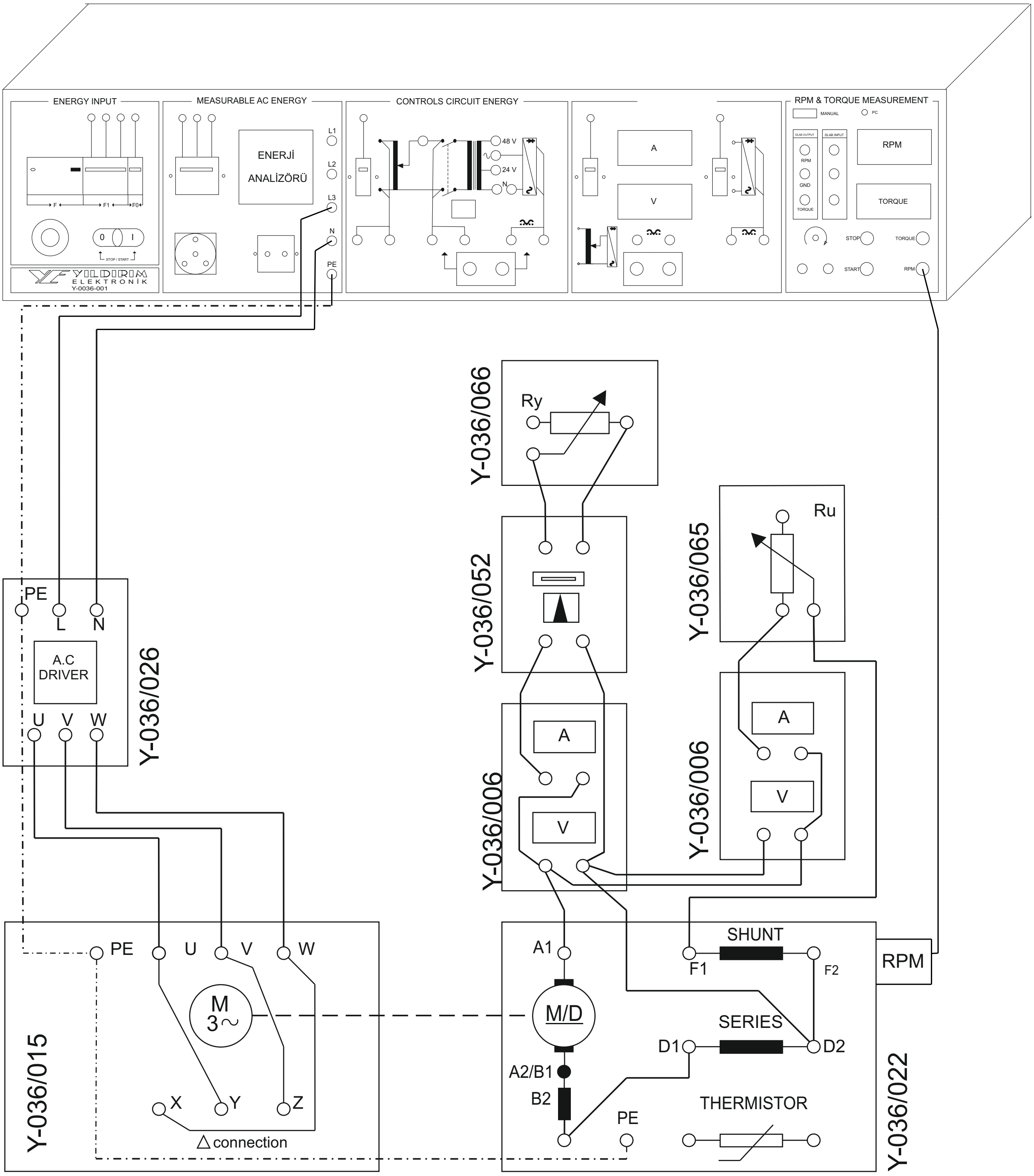


Figure 15.1:Connection diagram for loaded operation of the DC compound generator

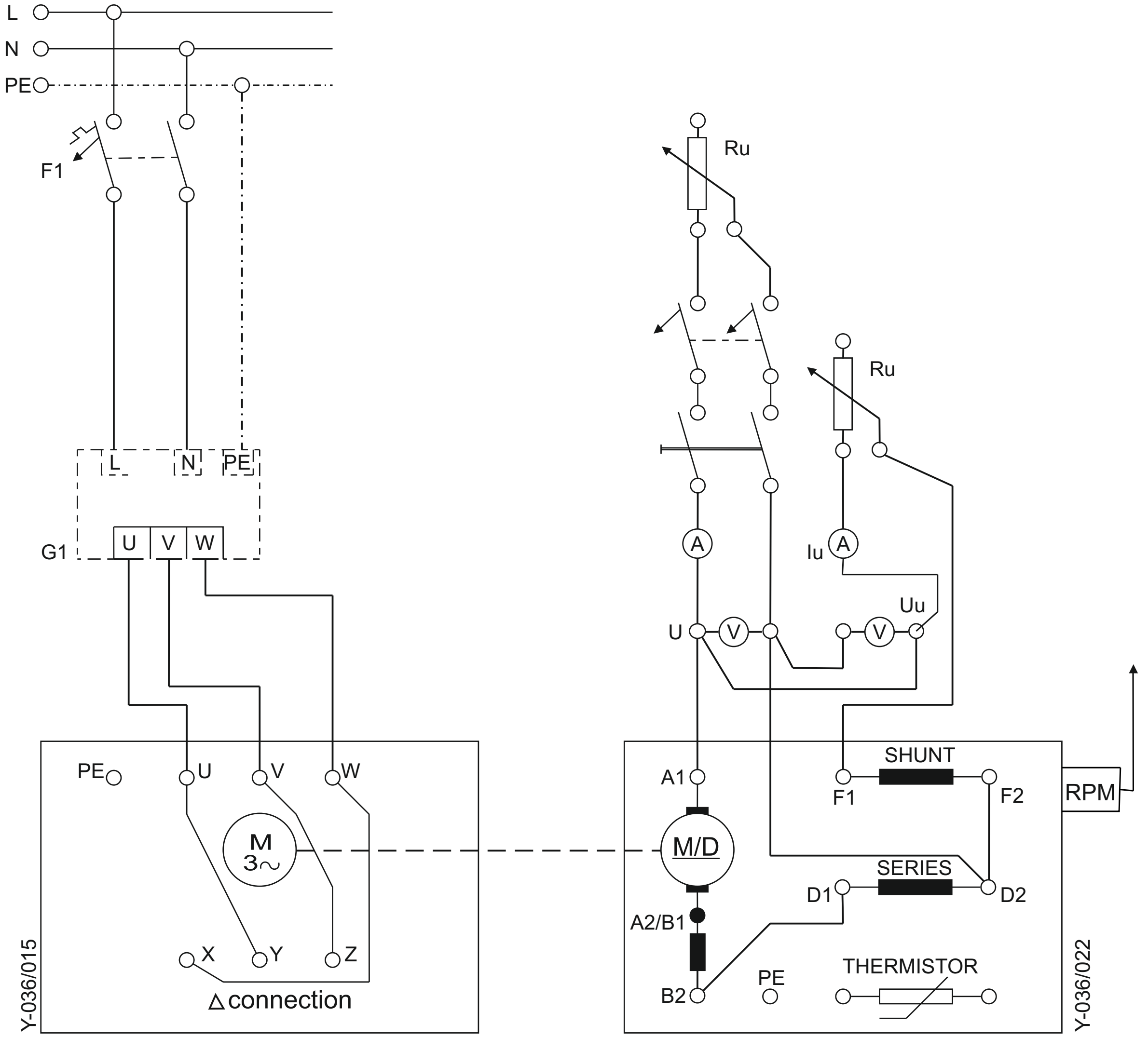


Figure 15.2:Connection diagram for loaded operation of the DC (commutative) compound generator

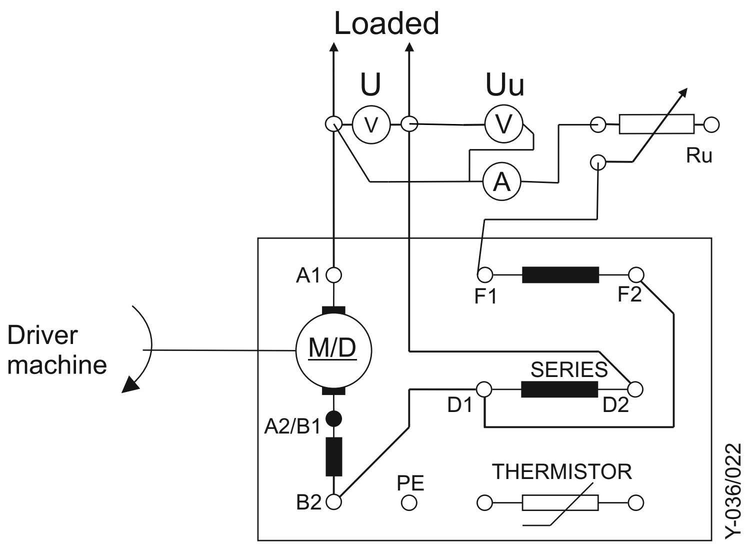


Figure 15.3:Figure 15.1:Connection diagram for the DC (differential) compound generator.

Procedure:

Not:∗Be careful about the rated values of the AC-DC machines.

∗The DC compound generator experiment will be performed using the cumulative compound generator circuit shown in figure 15.2. It can also be performed using the differential compound circuit shown in figure 15.3.

-Connect the circuit shown in figure 15.1 and 15.2.
-Set the speed of the DC generator to its rated value and take note of the speed.
-Set the voltage of the generator to its rated value using the excitation rheostat (Re). Without the load, take note of the values Ug, IL, Ue, Ie, and n.
-Connect the load circuit and load the generator by the load rheostat (RL) step by step. Keep n and the excitation resistance (Re) constant during the experiment. Take note of the values Ug, IL, Ue, Ie, and n in each step.
-Load the DC compound generator with 1.2 times the rated load. Use the lamp group if the load rheostat is not sufficient. Take note of the values Ug, IL, Ue, Ie, and n for that case.
-Turn of the energy and finish the experiment.
**You can optionally connect the differential compound circuit shown in 15.3.
-Repeat the same steps.
-Turn of the energy and finish the experiment.

Values recorded in the experiment :

n	U	IL	Ue	Ie	Explanation

Evaluation :

Question 1: Sketch the loading curve of the DC compound generator using the values recorded in the experiment for both cummulative and differential case.
Question 2: What does cummulative and differential mean for DC compound generator?
Question 3: In which applications these properties of DC compound generator are required to be used? Explain.
Question 4: How does the structure of the excitation windings determine the general structure of the DC compound generator? Explain.
Question 5: How should be the structure of the windings in order to use the DC compound machine both as a series and a shunt machine?
Question 6: State your final observations about the experiment.

GENERAL INFORMATION ABOUT ELECTRICAL MACHINES

2.1 - ELECTRICAL MACHINES :

Today, electrical energy is used widely in many areas of the industry and its usage changes rapidly. The usage of electrical energy in industry is provided by ELECTRICAL MACHINES.

To fully understand elecrical machines, it is necessary to have knowledge in electromagnetics, standing-moving conductor that current passes through it. These topics are covered in Electrical Machines - Circuit Analase (Electrotechnique) courses. ‘Electrical machines’ are handled as a high level phenomenon.

The content of the ELECTRICAL MACHINES is:

A-Dynamic Electrical Machines

1:DC Machines
a) D.C Generators
b) D.C. Motors.

2: A.C machines
I- Asynchronous motors
a) 3 phase motors
b)1 phase motors
II- Synchronous machines
a) Synchronous generator (Alternator)
b)Synchronous motor
3: Servo Motor
4: Step Motor

B- Static Electrical Machines

1- Transformers
a) 1 phase transformers
b) 3 phase transformers
c) Autotransformers

2- Rectifiers
a) Single phase rectifier
b) Tri- phase rectifier

We come across with the electrical machines as motor-generator-transformer, up-transformer and down-transformer according to usage.

1.2 STANDARD FABRICATION TYPE

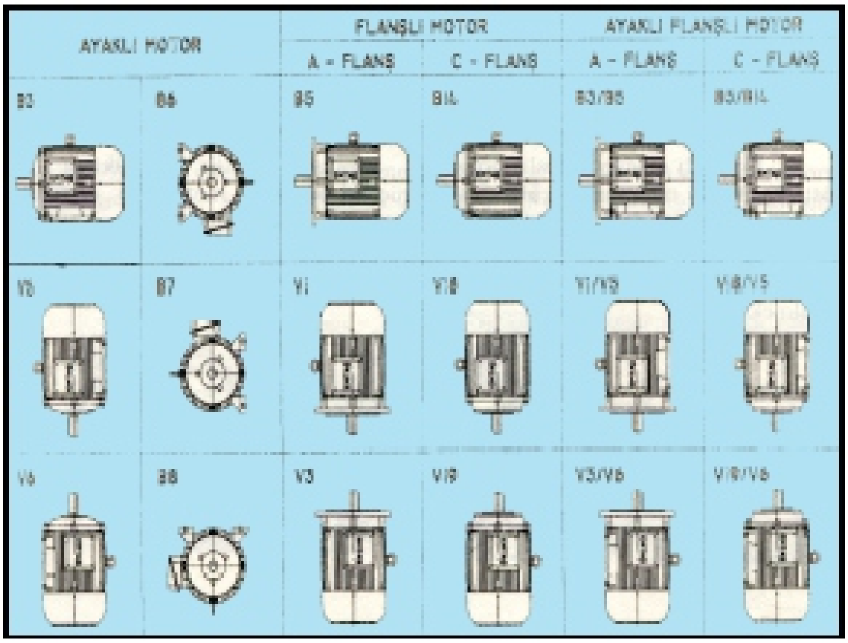


FIGURE - 2.1 Samples of fabrication types

The fabrication types of electrical machines are standard. There is a letter and a number following the letter as a symbol. (Figure: 2.1).

The symbol indicates information about storage, montage operation, shaft and excitation type. The detailed information about fabrication type can be obtained from the norm directives like TSE-DIN-IEC etc.

2.2 - STRUCTURE

The stationary part of the rotating electrical machines is called STATOR, and the rotating part is called ROTOR. The static electrical machines are composed of the core and the PRIMARY-SECONDARY windings around it.

The structure of the electrical machines is divided in to two parts as; the magnetically and electrically conductive part and the construction part.

2.3- COOLING AND WINDING:

There occure heat loss in dynamic electrical machines. This effect must be limited or it must be eliminated up to thermic level. The high temperature damages the isolation of the windings. As a result the machine becomes unusable.

There are generally cooling systems in the electrical machines. Also the cooling fan which is connected to the rotor transfers cool air to the required parts of the machine. Similarly, the upper face of the body of the machine gives the heat out.

In transformers, the cooling and winding operations are perormed by oil and a fan motor.

2.4-ISOLATION TYPES:

The windings of the standard electrical machines is produced from varnished conductor. Those machines can work under high temperatures. Therefore, there are some isolation types depending on the maximum accepable temperature.

Isolation type	Maximum allowed temperature
Y	90^0
E	120^0
F	155^0
H	180^0

Figure- 2.2

2.5 : THE OPERATION CHARACTERISTICS OF THE MOTORS

The operation characteristic of the motors is determined by the torque and the number of rounds per minute (rpm). The rpm value is higher in no-load case compared to the loaded case. The change in the rpm value is 5 % of the rated value. The operation characteristic of the dynamic electrical machines can be studied in groups of four.

1 Synchronous operation properties :

The change in the rpm value is zero. It does not change with the load.

2. Shunt operation properties:

The change in the rpm value is smaller than 10 %;
DC shunt motor,
Single phase and Asynchronous motor
Three phase shunt motor.

3. Compound operation properties :

The change in the rpm value is between 10 %-20 %.
Squirrel cage three phase motor
DC Compound motor.

4. Serial operation properties:

The change in the rpm value is greater than 25 %;
DC Serial motor,
Single phase serial motor.

2.6 : THE DIRECTION OF THE ROTATION:

The direction of the rotation of the dynamic electrical machines is always seen by observing the motor shaft at the excitation part. When the rotor is rotating right, it rotates in clockwise direction. When it is rotating left, it rotates in counter clockwise direction.(Figure 2.3) the motor has two parts. One part is A, the other is B.

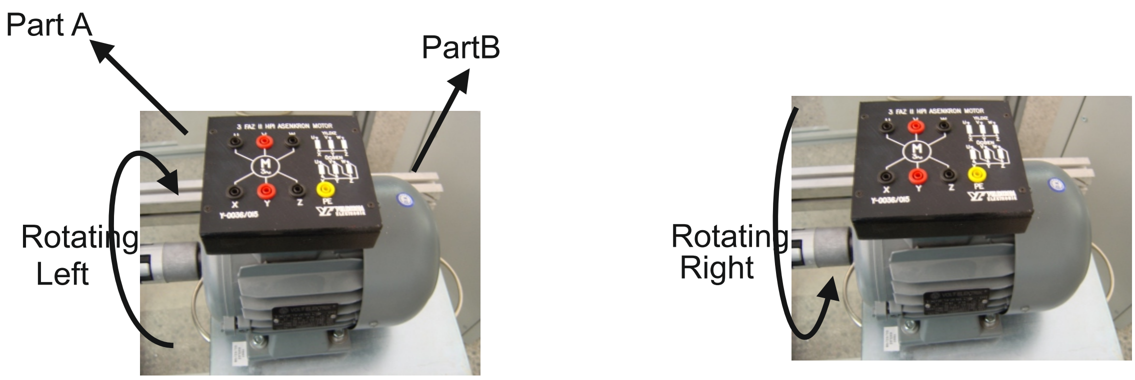


Figure 2.3 The direction of the rotation of the motor

Part A

a) Excitation shaft
b) The part with the greater shaft radius, if they are unequal.
c) The part opposite to the ring or commutator if the radiuses are equal.

Part B

a) The part with the fan (Fan may be in part A in specific machines.
b) The part with the smaller shaft radius
c) The part with the ring or commutator

2.7 THE CRITERIA FOR CHOOSING MOTOR AND OPERATION TYPE

The operation type has priority in selecting the electrical motor. For example; the motor warms up less when loaded for short duration compared to long duration. Therefore, a motor with less power maybe chosen.

The properties of operation types from S1 to S9 are:

S1 Continuous operation

The motor can operate until reaching the temperature limit under normal load conditions. Those types of motors are suitable for continuous operation. Which means they can operate continuously with rated load. (Figure: 2.4)

S2 Short time operation (KB)

The operation time is too short to reach the temperature limit when it is compared with the following stop time. In the long resting time following the operation time, the motor cools down until reaching the temperature limit on its own. (Figure: 2.5)

S3-S4-S5-Irregular operation (AB)

The resting time is short. Those durations are not long enough to reach the room temperature. (Figure: 2.6)

S3 : It indicates that the heat caused by the starting current is intolerable for the motor.
S4 : It indicates that the heat caused by the starting current is tolerable for the motor.
S5 : It indicates that the motor is heated additionally by the braking current.

S6 Irregular loading, continuous operation(DAB) :

The no-load operation duration is not enough for the motor to be cooled down. (Figure: 2.7)

S7 Start and brake discrete operation:

There is no stop practically. The voltage is applied to the motor continuously. The number of pulses per hour must exceed a specific value.

S8 Discrete operation with switching polarization :

The motor generally operates with varying rpm values under permanent loads.

Discrete operation under aperiodic load and varying rpm value:

The motor can be loaded over the rated value in the form of pulses.

P= Power, φ= Motor temperature

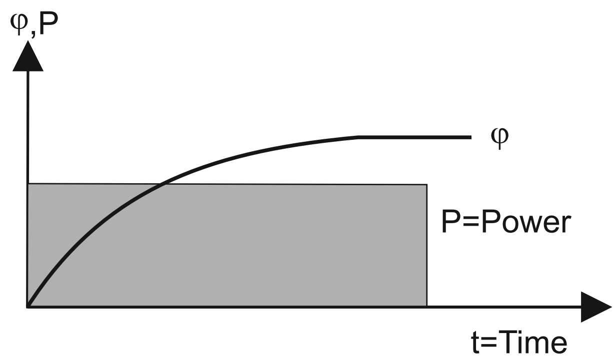


Figure: 2.4contunious operation (DB)

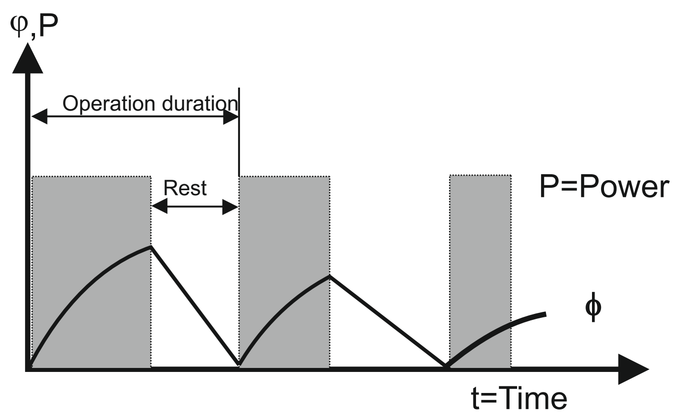


Figure:2.5 short time operation (KB)

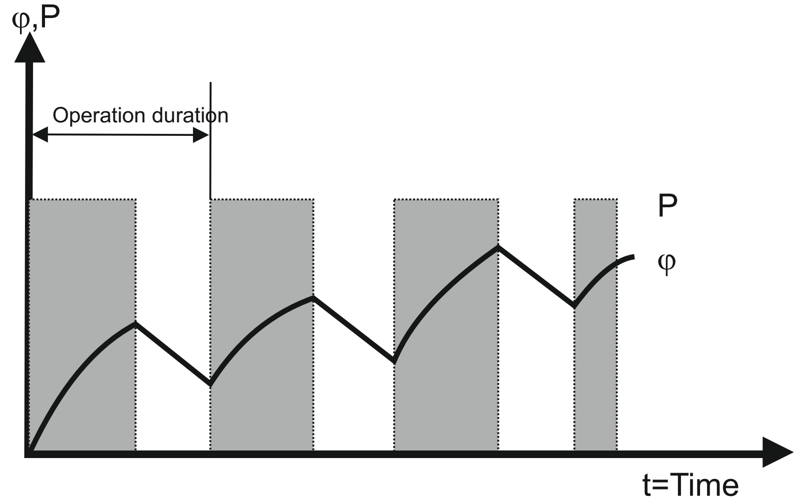


Figure:2.6 Irregular operation (AB)

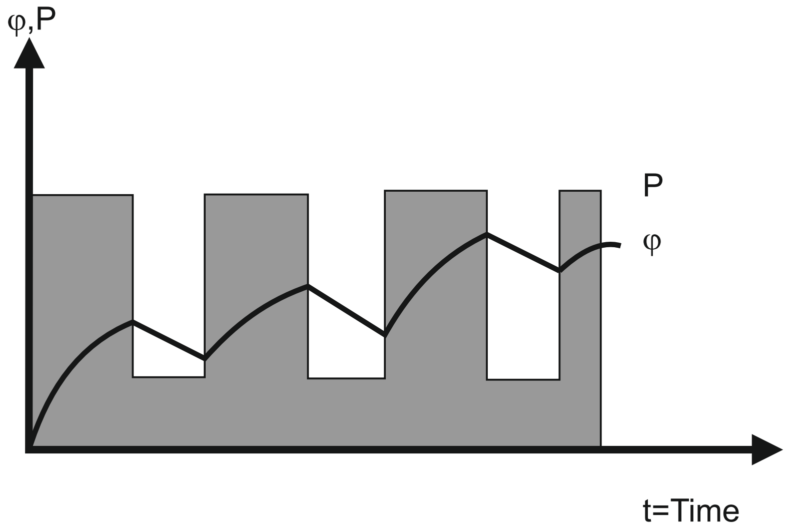


Figure:2.7 Irregular loading, continuous operation (DAB)

2.8 PROTECTION TYPES AS AN INDICATOR OF SAFETY

By the protection type, important fabrication regulations and standards are followed, people (the workers) are protected from touching the parts with high voltage and motor is protected from undefined objects and water. The protection type is indicated by two numbers following the letters IP (International Protection)

The first number indicates the protection against the undefined object and touching. The second number indicates the protection against water.

Various protection types according to EN 60259 and VDE symbols belonging to those protection types are shown below.

Protection against touching and undefined objects

IPOX, Touching protection
IP1X, Protection against undefined objects> 50 mm Ø
IP2X, Protection against undefined objects> 12 mm Ø

IP3X, Protection against undefined objects> 2,5 mm Ø

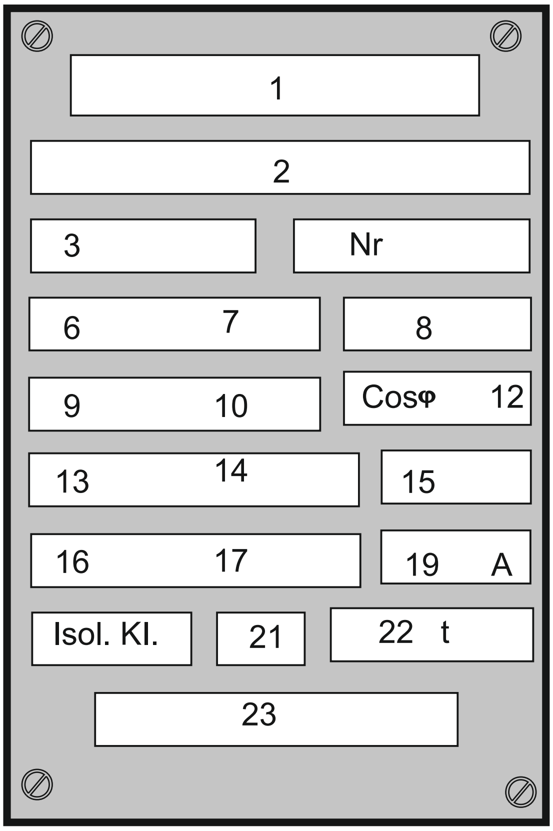
IP4X, Protection against undefined objects> 1 mm Ø
IP5X, Protection against internal dust accumulation
IP6X, No diffusion of dust

Protection against water

IPXO, No protection against water
IPX1 , Protection against vertical water drop
IPX2 , Protection against water drops falling down with a slope up to 15°
IPX3 , Protection against water drops falling down with a slope greater than 30°
IPX4 , Protection against water drops from all directions
IPX5 ,△△ Protection against water spraying
IPX6 , Protection against flood
IPX7 ,△△ Protection against diving in to water
IPX8 ,△△Protection against diving in to deep water
IP20 , Protection against undefined objects > 12 mm, no water protection
Ip54 , Protection against internal dust accumulation, protection against water drops from all directions

2.9 POWER LABEL FOR THE USER INFORMATION:

All the important characteristic values of electrical machines are indicated in the power label. These information is the identity of the machine. They are required when choosing the machine. The power label for dynamic and static machines is given in figure 1.10/a-b and standard explanations are given in Figure 2.9/a-b.



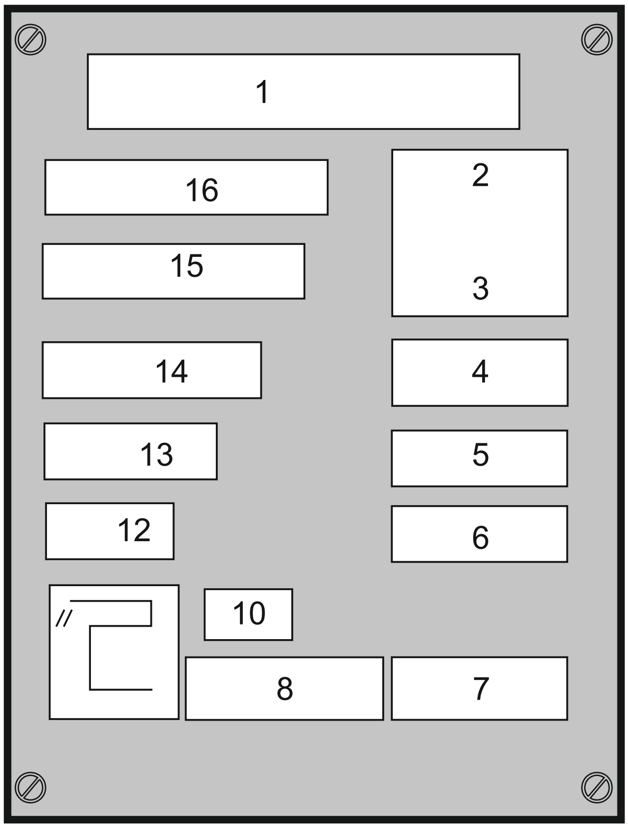


Figure :2.8/a Power label for dynamic electrical machine Figure :2.8/b Power label for static electrical machine (transformer)

Area Number	Explanation (Characteristic value)
1	Producer company name
2	Type symbol
3	Current type
4	Operation type
5	Production serial number
6	Stator winding type
7	Rated voltage
8	Rated current
9	Rated power
10	Power unit (W or KW)
11	Operation mode
12	Rated power factor
13	Rotation direction
14	Rated rpm value
15	Rated frequency
16	Excitation information
17	Armature winding type
18	Rated excitation voltage
19	Rated excitation curent
20	Isolation type
21	Protection type
22	Weight (for heavy machines)
23	Extra information

Figure 2.9/a
Dynamic machine power label explanation

Area Number	Explanation (Characteristic value)
1	Producer company name
2	Rated primary current
3	Rated secondary current
4	Rated power
5	Connection type
6	Winding ratio
7	Core type
8	Isolation type
9	Protection type
10	Rated frequency
11	Connection
12	Primary technical short circuit current
13	Secondary technical short circuit current
14	Experiment voltage
15	Type
16	Fabrication date

Figure 2.9/b
Static machine power label explanation

2.10 CONNECTION SYMBOLS:

Connection symbols are standard. These symbols consist of capital letters and numbers. In the numbers, (1) indicates the beginning of the winding, (2) indicates the end of the winding. Terminals are expressed with numbers 3-4. The symbols for A.C. and D.C machines (for that book) are given below.

Alternating current machines	
Stator star circuit (⅄)	U1-U2 (U-X) V1-V2 (V-Y) W1-W2 (W-Z)
Stator delta circuit (△)	U1-V2 (U-Y) V1-W2 (V-Z) W1-U2 (W-X)
Star point	N
Rotor winding	K,L,M
Ground	PE

Figure 2.10 A.C. Machine connection symbol list

Direct current machines	
Core	A1 – A2
Auxiliary polar winding	B1 – B2
Compensation winding	C1 – C2
Serial excitation	D1 – D2
Shunt excitation	E1 - E2
External excitation	F1 – F2

Figure 2.11 D.C. Machine connection symbol list

2.11 EFFICIENCY AND LOSSES:

Efficiency (η) is the ratio of the output power to the input power.

$$\eta = Po / Pi$$

There occur losses in every electrical machine operation. Therefore the output power is always less than the input power. The losses are due to friction, resistance of windings, eddy currents in the stator and rotor. These losses are represented by Pl for general case, Plfe for iron losses and Plcu for copper losses.

There is no friction loss in the static electrical machines (transformers). Therefore, the efficiency is greater than 90 %. In dynamic electrical machines the output power is determined by the rpm value and the torque.

$Pa = 2\pi.T.n$
T: Torque(Nm)
n: rpm (rounds per minute)

The power of the static electrical machines is the output (secondary) power.
$Ps = Us.Is.\sqrt{3}.Cos\varphi$
Us: Secondary voltage (V)
Is: Secondary current (A)

The power applied to the tri-phase motor is:
$P = U.I.\sqrt{3}.Cos\varphi$
U : Voltage(V)
I : Current(A)
$Cos\varphi$: Power factor

Pi and Po must be measured at the same time and condition. The real efficiency value is obtained only in that way. The efficiency takes its maximum value in rated operation.

3. DIRECT CURRENT MACHINES

3.1 STRUCTURE OF THE MACHINE

They are the machines that operate according to the following principle: A conductor moves in a uniform magnetic field. Therefore current is induced in the conductor. That current is rectified by the ring and brush and send to the output circuit.

∗If D.C voltage is applied, they operate as D.C motor;

∗If mechanical energy is applied they operate as a D.C generator.

The structure of the direct current machine is given in figure 1. It is composed of a steel body (magnetic field body) called STATOR, a steel sheet group (main pole), pole slips and excitation windings. The excitation windings are used to create a uniform magnetic field. In powerful machines, direction change poles and compensation windings are used additionally.

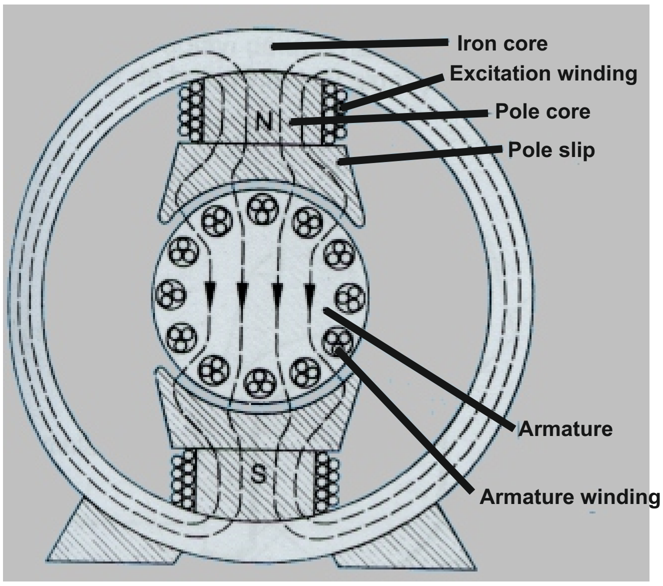


Figure 1: The structure of the direct current machine

The armature, which is also called as rotor, is composed of the armature windings placed into slots at the steel sheet group around the shaft and the current converter (also called collector) around the shaft (Figure 2). The current is transferred to the armature through the collector.

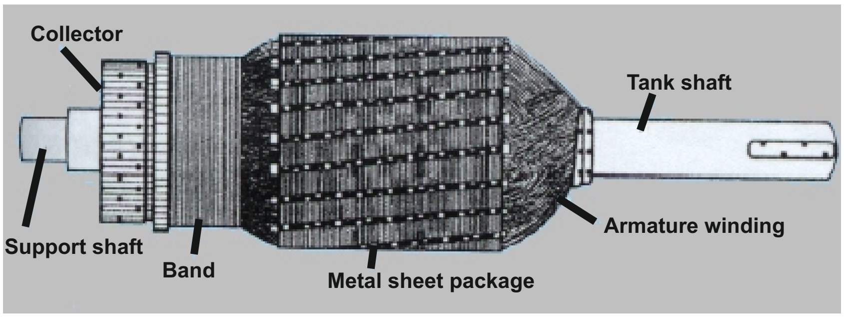


Figure 2 : The armeture of the direct current machine .

Each armature winding is connected to the collector slices. (figure 3).
Each of the A….F single turn windings represent a single winding.

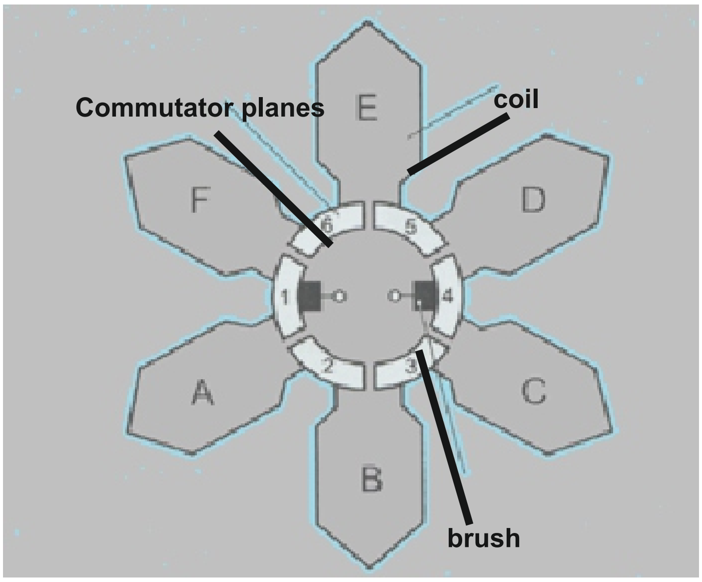


figure 3 : commutator and brush

Commutator is produced by pressed copper plates with mica insulators in between. The current is transferred to the armature through the carbon brushes (Figure 4).

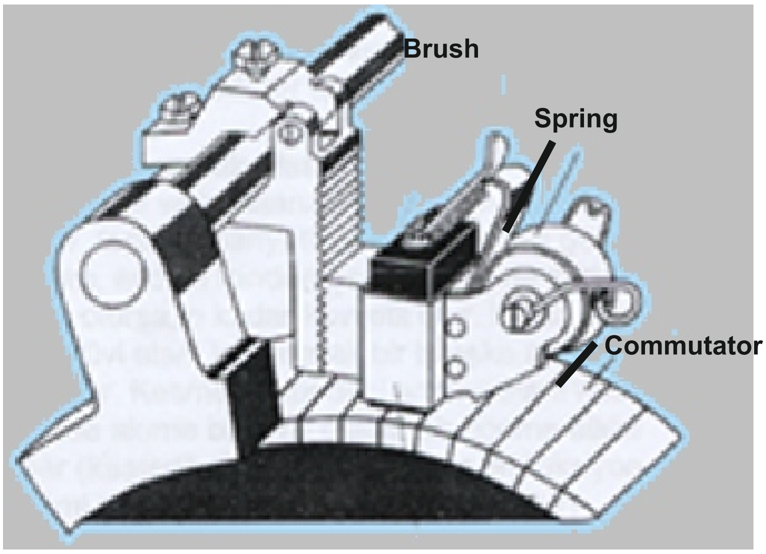


Figure 4: A part from the carbon brush an commutator

3.2 Operation of the commutator:

If voltage is applied to the terminals of the coils of the simple mechanism (motor winding) shown in figure 5, there appears a force on the coil. Also a torque appears. Therefore the coil rotates a little bit in the horizontal plane. The direction of the current must be reversed in each half cycle in the armature in order the coil to rotate in the stator field continuously in the same direction. That is achieved by the commutator. In the following figure, it is shown that the commutator consists of two isolated semi-cylindric pieces connected by winding conductor. When the coil rotates, the current in the commutator and the coil change direction.

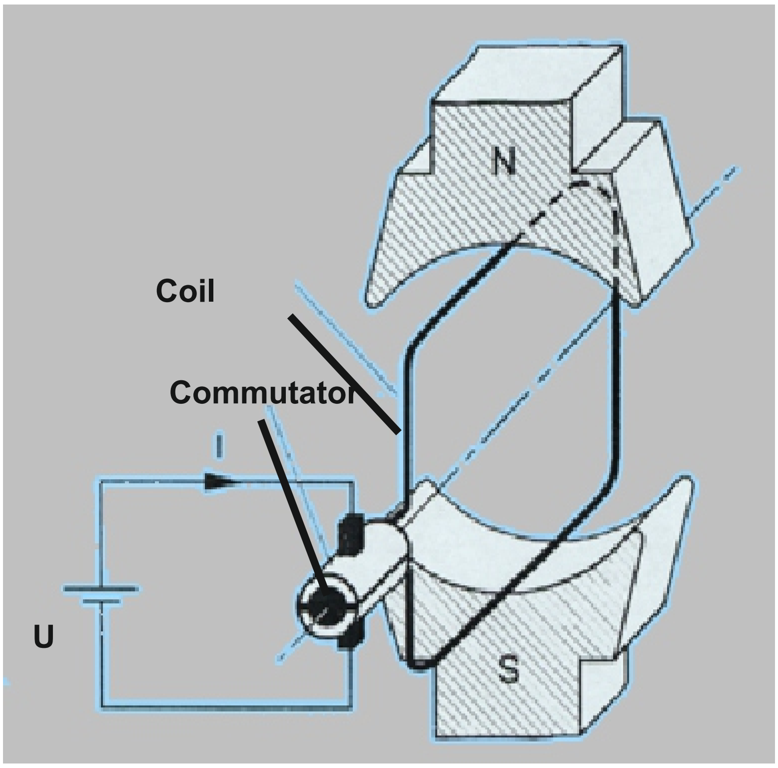


Figure 5: The operation of the commutator

3.3 Operation of the D.C machine :

The operation property of the D.C machine is basically understood from the relation of the rpm value and torque at different loads. Big pulling forces are produced in DC machines. Their rpm value can be varied continuously. Their operation structure depend of the type of the machine. That will be covered in the following chapters.

3.4 The fields in the direct current machine:

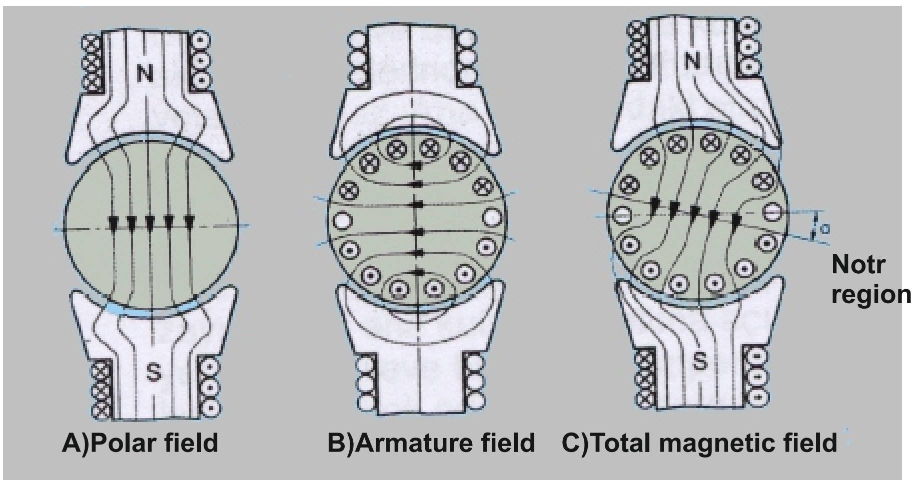


Figure 6 : The fields in the direct current machine

a- Pole field :

The pole field is created by electromagnets in most of the direct current machines used today. The coils inside the stator are the pole field coils. That field closes its circuit through the armature sheet package.

b- Armature field :

A magnetic field is created through all the conductors that carry current in the armature. If current flows in the same direction in parallel conductors, all the created magnetic fields align in the same direction. That net magnetic field crosses the pole field.

c- Total magnetic field :

The total magnetic field is summation of the pole field and the armature field. The magnitude of that field depends on the current passing through the armature. The total resultant magnetic field is formed by the summation of the pole field and armature field. The armature field in the direction of intersection causes rotation depending on the natural field current. (The voltage induced in the armature does not appear on the natural field.) The natural axis rotates as much as the increase in the current passing through the armature.

Armature reaction:

The effect of the armature field on the pole field is called armature reaction. That effect rotates the natural region and causes pole field to weaken. In motors with no-load, the pole field is symmetric with respect to the pole slips. The main pole field decreases and the natural region rotates as much as the increase in the load. The magnetic induction increases near the poles and it becomes zero between the poles. The region with zero induction is the natural region. The brushes must be in that region. Arcs with high energy appear in the brushes because the armature supply current flows out of the region without induction. That arc damages the commutator and the carbon brushes. Therefore the arc becomes stronger, the temperature rises and the armature windings are damaged. In order to prevent that situation the brushes must be kept in the natural region and they should be adjusted according to the load. That is not possible for the variable loads. So that, auxiliary poles are used to prevent the change in the natural region.

D.C machines with auxiliary winding:

The auxiliary windings are placed between the main poles. The auxiliary windings are connected in series with the armature windings and they create magnetic field with the same magnitude but in opposite direction to the armature field. Therefore the natural region keeps its position even if the load changes. Also the armature field in the natural region disappears.

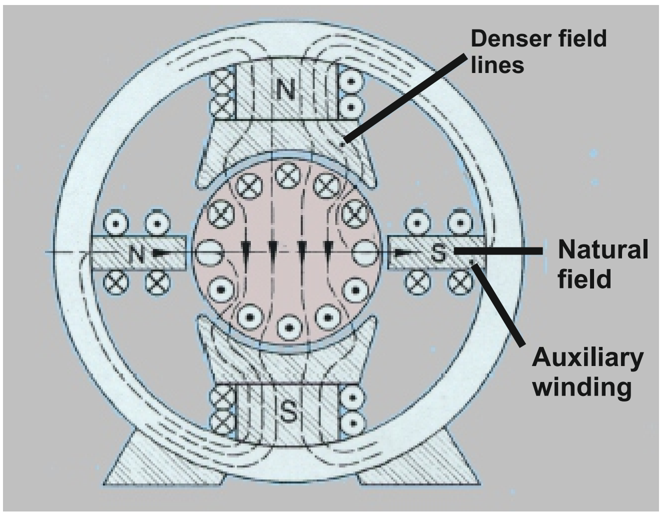


Figure 4 : D.C machine with auxiliary winding

D.C Machines With Compensation Winding:

The auxiliary windings are not sufficient for the machines with bigger loads and power. The weakening in the main field causes the saturation in the corners of the poles. That situation causes some problems in the armature windings. That weakening is compensated by placing compensation windings into the slots under the main poles. That windings must be placed opposite to the direction of the armature current.

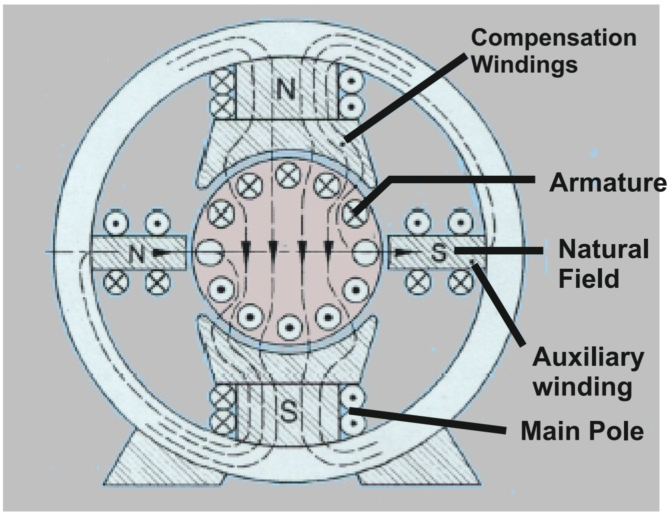


Figure 8: D.C Machine with Auxiliary and Compensation windings

Other Ways of Preventing Armature Reaction :

Producing poles in a form like dredge,
Opening slots in the slots

Commutation:

It is the effect that appears when the current in the armature windings change direction. The direction of the current flowing in the armature windings must be changed by the commutator and the brush. Otherwise an arc appears in the brushes. That situation causes problems in the armature windings, commutator and brush.

In order to deal with these problems, the commutation must be enabled.

Factors That Corrupt Commutation:

Round shape of the commutator ,
The corrosion in the copper commutator slices,
The brushes to get caught in the brush holders,
The brushes not to press on the commutator sufficiently (150-250 gr/cm²),
The oxidation of the brushes,
The unbalanced armature,
Unequal distance between the brushesı,
The unequal distance between the armature and the poles,
Low carbon concentration and resistance of the brushes

Methods Used for Commutation:

Using brushes with high carbon concentration and resistance,
Slipping the brushes,
Using auxiliary winding (connected in series with the armature)

3.5 : Methods for Starting DC Machines:

If the DC machines are directly connected to the network, it is necessary to have initial torque. The resistance of the armature windings are small. therefore the current at starting is 10-20 times greater than the rated value. That situation is dangerous for the windings. But when the armature starts rotating, a reverse voltage is induced. That voltage increases with the speed of the rotation. As a result the current decreases.

The high starting current can be prevented by connecting a starter rheostat in series with the armature. The resistance of the rheostat is decreased while the motor is speeding up. When the rated speed is achieved, the rheostat is short circuited. That starting method is not efficient since the energy is converted into heat in the rheostat. As an alternative, variable voltage supplies are used not to waste energy. In that case it is possible to do more sensitive speed control.

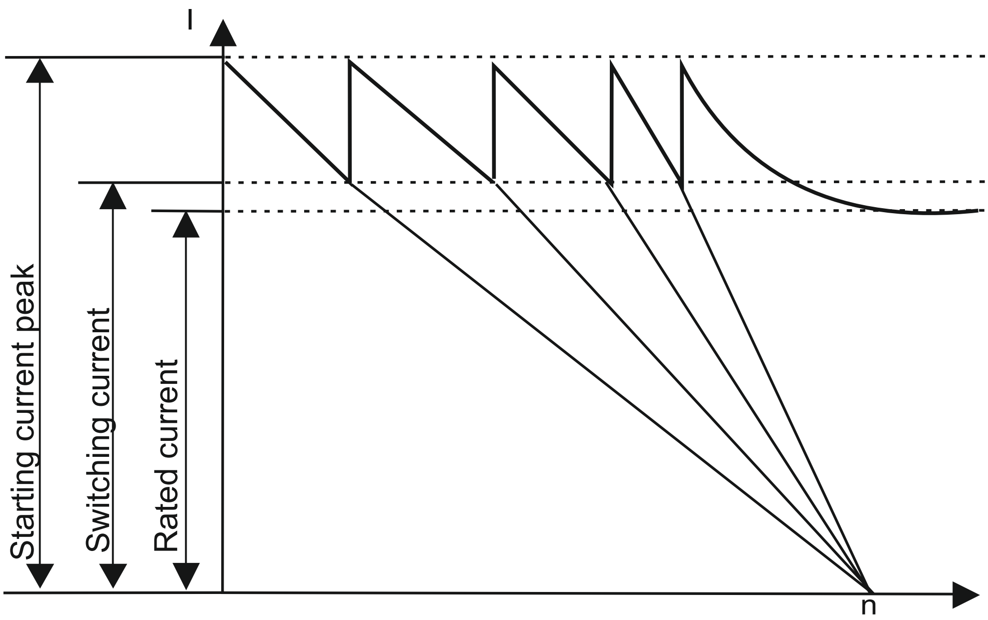


Figure 9. Limitation of the Starting Current with Four Step Starting Resistance

3.6 : Speed Control of the D.C Machines:

Speed control may be necessary in two systems. Two methods are used for speed control.

1- Changing speed with voltage control:

If it is desired to have speed values from zero up to a specified voltage, the speed is controlled by the armature voltage. In that method the field must be excited. The speed of the motor decreases if the armature voltage decreases or the load increases. In that method the efficiency decreases because of the serially connected resistance. The starting resistance must have fine control.

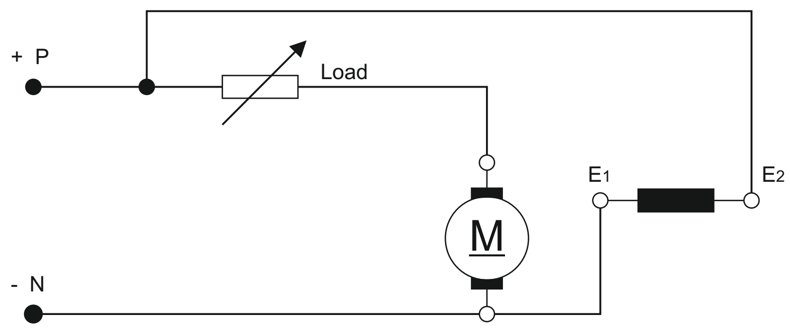


Figure 10.Changing Speed By Controlling Armature Voltage

Using thyristor controlled rectifiers is more efficient in speed control. A constant DC voltage can be obtained from network voltage by using that circuit without any loss. In that system a constant DC voltage must be applied to the excitation windings.

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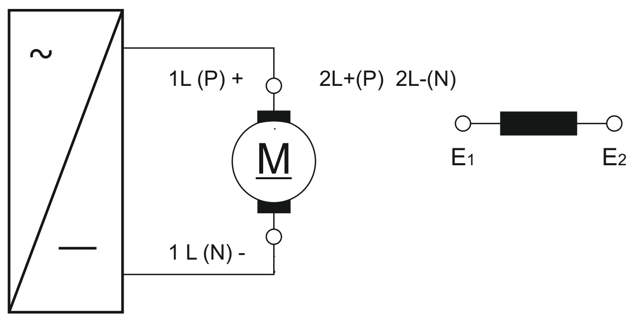

Figure.11 .Speed Control with Thyristor Controlled Rectifier

2- Field Control:

The speed of the DC machine can be controlled by varying the resistance connected to the excitation windings. In that method the armature or the commutator may be damaged because of the decrease in the field strength. Therefore that method must be used with some limitations.

The excitation current must never be discarded. Otherwise the speed of the motor goes to infinity and the motor breaks down. The torque decreases a little bit while changing the speed with field control.

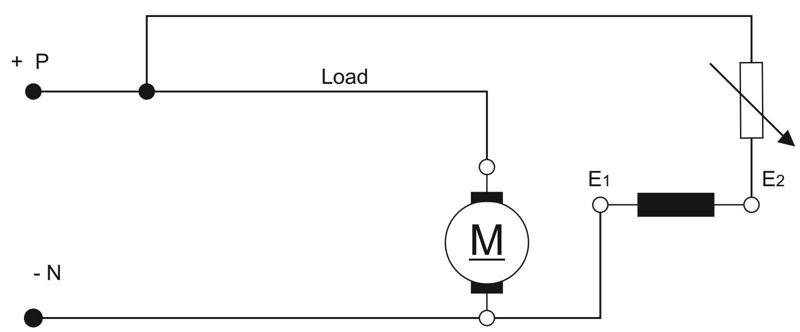

Figure.12. Changing Speed with Field Control.

3.7 Changing Direction of Rotation of D.C Machines:

The rotation direction is changed by reversing the armature or excitation currents in all types of DC machines. Generally the armature current is reversed.

3.8 Types of D.C Machines:

D.C Shunt Machines:

The DC shunt machines are fabricated as self excited or separately excited. In self excited shunt machines, the excitation and the armature windings are supplied with the same DC supply. In separately excited shunt machines the excitation and the armature windings are supplied from separate DC supplies.

In an other type of the shunt machines, the only winding is the armature winding and the excitation field is created by permanent magnets. Shunt machines are used in control systems and model fabrication. DC shunt machines are used as DC shunt motor and DC shunt generator.

D.C Series Machines:

In DC series machines the armature and excitation windings are connected in series with each other. Since all the current passes through the excitation windings during the operation, the resistance of the armature and excitation windings must be small. The starting current of the DC series machines is very high. Therefore it must be limited by an starter mechanism.

The DC series machines have very high starting torque. Therefore they are widely used in electrical vehicles and automotive industry.

In DC series machines, the speed is inversely proportional to the load. The speed decreases with the increasing load.

The main disadvantage of series DC machines is that they should not be operated at no-load. At no-load the speed goes to infinity and the machine is damaged seriously.

DC series machines should not be operated at no-load. They are used as DC series motors and DC series generators.

D.C Compound Machines:

In DC compound machines series and shunt windings are used together. For that reason the compound machines have the properties of both series and shunt machines.

The compound machines' speed is not stable likewise the shunt machines. It does not vary much likewise the series machines. The machine does not break down when it is operated at no-load and the excitation windings are fully excited.

DC compound machines are used when mechanical output in the form of pulses is necessary (punch press machine). They are used as DC compound motors and DC compound generators.

3.9 Connection symbols of the D.C Machines :

The connection symbols of the DC machines consist of a number and capital letter. These signs and their meaning is given below.

A- Armature winding
B- Auxiliary winding
C- Compensation winding
D- Series excitation winding
E- Shunt excitation winding
F- Separate excitation winding

1- Winding start
2- Winding end
3- Pin
4- Pin

3.10 Braking Methods in DC Machines :

The following braking methods are used in shunt-series and separately excited machines.

Braking with Resistance:

In that braking method, the armature windings of the separately excited shunt machine are disconnected from the supply and they are shorted via a resistance. It is possible to brake rapidly by selecting that resistance smaller. That method is used in winch systems.

Servo Brake:

In servo brake the direction of the rotation does not change. The machine excites itself because of the magnetization. Current passes through the armature windings. The direction of that current is opposite to the voltage induced. At that instant the machine operates as a generator and it brakes. In that method the speed is smaller than the rated speed. If that method is applied to series machines, the direction of the excitation current must be reversed in order not to annihilate the excitation. Servo brake is generally used in electrical vehicles.

Braking by Decreasing the Load:

In that method the speed decreases if the load is decreased. The energy produced at that instant warms up the resistances or it is given to the network. The polarization of the excitation windings must be reversed if that method is used in shunt machines in order the excitation not to disappear. That method is generally used with series machines.

Braking by Reversing the Current:

That method is applied by reversing the armature current. The power transferred at that instant may be greater than the power produced because of the braking. Therefore the thermic resistance of the machine must be great.

The current may be greater than the rated current. The braking duration must be small.

EXPERIMENT 1 :FINDING THE EMF INDUCED IN THE ARMATURE

PURPOSE: Understanding induction, movement of a conductor in the magnetic field. Deriving the equation of the emf induced in the coil.

EQUIPMENTS:

U magnet
I magnet
Coil
Galvanometer (zero in the middle)

CONNECTION DIAGRAM FOR THE EXPERIMENT:

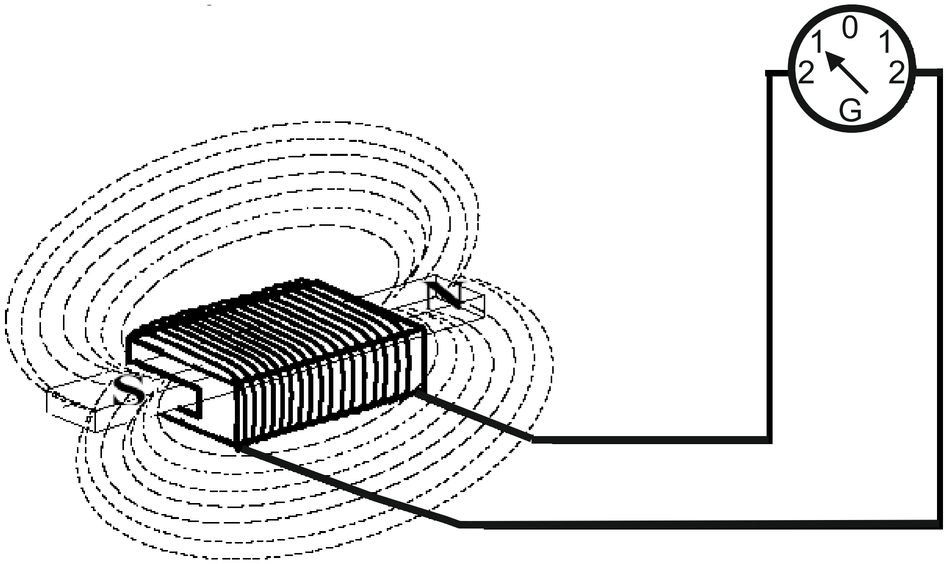

Figure1 :Connection (induction) diagram for the experiment .

If a conductor moves perpendicular to field lines of a magnetic field, voltage is induced across that conductor. Also it is possible to induce voltage by moving the magnet while the conductor is stationary. That voltage is called emf. The magnitude of the voltage induced depend on the magnetic field strength, the number of turns of the coil and the speed of the movement.

The emf induced on the conductor is;

$$e = B \, . \, l \, . \, v \, . \, \text{Sin}\propto \, . \, 10^{-8} \text{ Volts}$$

PROCEDURE:

-Connect the circuit shown in the figure.
-Move the magnet inside the coil.
-Speed up the magnet.
-Move the coil while the coil is stationary.
-Repeat the experiment by using a stronger magnet.
-Laboratory is made in accordance with possibilities!

EVALUATION:

QUESTION 1 : Explain induction.
QUESTION 2 : Explain the factors that affect the induced voltage.
QUESTION 3 : What did you observe when you used a stronger magnet? Explain.
QUESTION 4 : Explain the effect of stronger magnet on the induced voltage.
QUESTION 5 : Explain your final observations.

4. D.C SHUNT MACHINE:

DC shunt machines are used as generators or motors. They are the most widely used type of machines practically. They are used where constant speed is desired for varying loads. (winch, pump, etc.)

They have the basic structure of DC machines. Their excitation windings and armature windings are connected in parallel with each other. They are supplied with same source.

They can also be operated as separately excited. In that case the excitation windings are supplied with a different source.

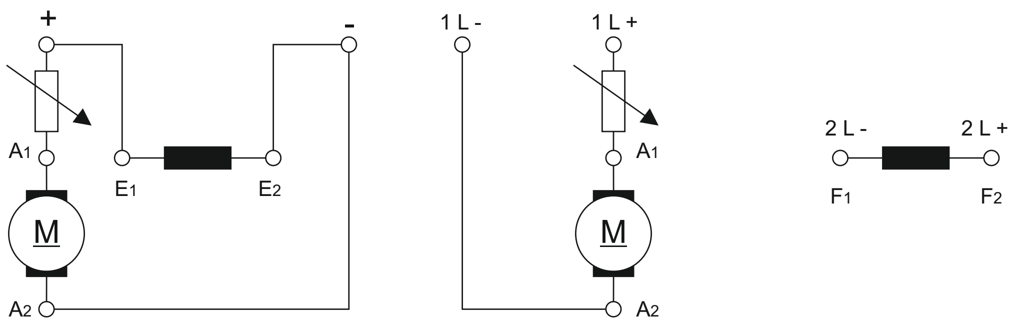

Figure 4.1 : Circuit for shunt machine

4.2 Motor operation characteristic:

The speed of the DC shunt motor is almost constant, when it is loaded. At no-load operation, they are stable and their speed is maximum. These are the characteristic properties of the Dc shunt motors.

The current passing through the excitation windings is same for loaded and no-load operation. The magnitude of the armature current depends on the load. Therefore, the change in the load affects the armature current. The torque of the motor is directly proportional to the armature current. That will be clearly seen if the following loading curve is analyzed.

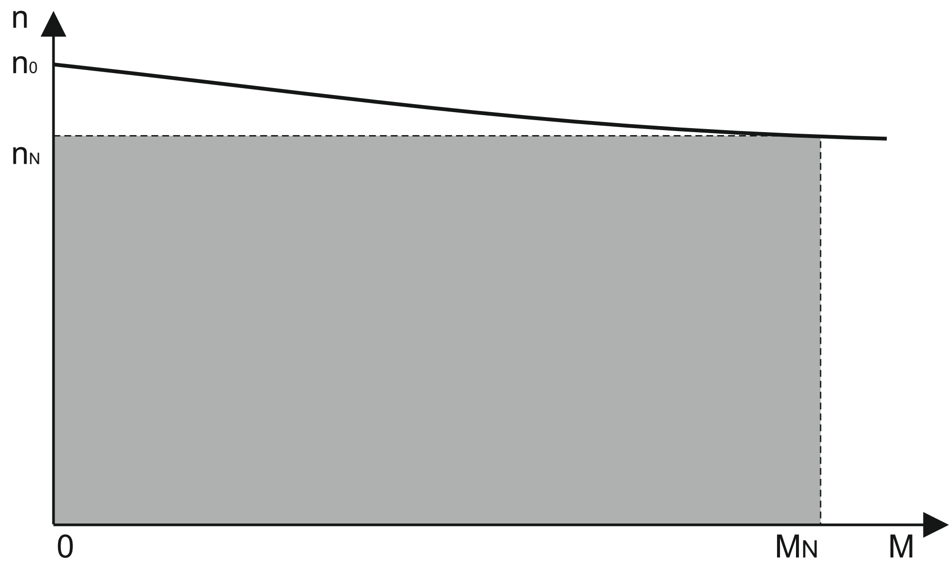

Figure. 4.2. D.C shunt loading curve

4.3 : Generator operation characteristic:

When a DC voltage is applied to the field windings and the armature is rotated; a voltage is induced and the DC machine operates as a DC shunt generator. These machines can operate as self excited or separately excited.

Separately excited DC shunt generator:

The field winding (F1-F2) of the DC shunt generator is excited separately. The amplitude of the excitation current is controlled by the excitation voltage through the armature. If the armature is loaded, the voltage across it decreases.

While the armature is loaded with a specified load, the desired value is obtained by increasing the excitation current.

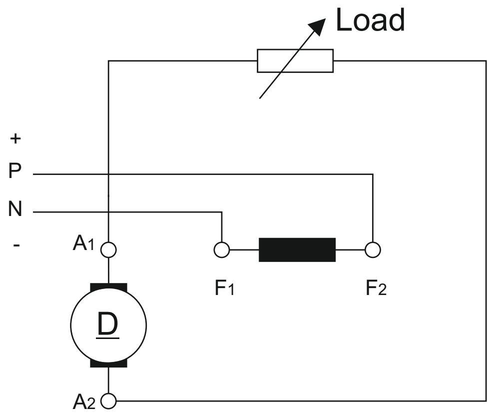

Figure- 4.3 Separately excited DC shunt generator

Self excited Dc shunt generator:

In self excited DC shunt generators the excitation windings are connected in parallel with the armature windings. Due to the residual magnetization in the iron core, a voltage is induced when the armature starts rotating. That induced voltage increases in a way to increase the magnetization and current passes through the windings. That current increases the excitation. So, the generator is excited by itself. The requirements of self excitation :

*residual magnetization
∗Correct polarization of the excitation windings.
∗Correct DC shunt generator rotation direction

The wrong polarization annihilates the residual magnetization. The machine can not be excited by itself. The generated voltage is decreased by the load in self excited generators. In order to prevent that decrease in the generated voltage a field controller (rheostat) is connected to the excitation circuit.

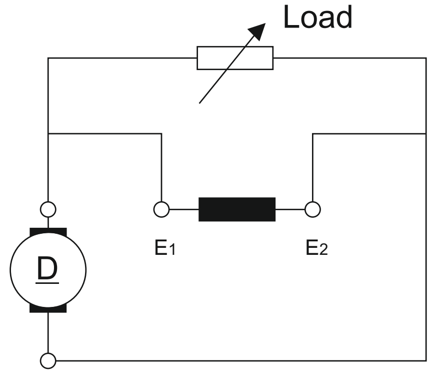

Figure. 4.4 Self excited DC shunt generator

4.5 : Starting the machine:

A starter mechanism is necessary in order to induce a voltage in the armature and start the motor. Without a starter mechanism, the motors pulls current 20 times greater than the rated value when starting. Therefore it is necessary to use a starter resistance. Or, a variable DC supply can be used for the armature voltage supply. Today, phase control systems with thyristors are used to obtain an efficient starter mechanism.

Important note:

The excitation voltage should not be in discarded DC shunt separately excited machines during the operation. Otherwise, the machine operates with a speed higher than the rated value which is harmful.

4.6 Machine connections :

The armature windings (A1-A2) and the excitation windings (E1-E2) are directly the terminals of the shunt machine. The same excitation windings are used in the separately excited operation mode. It is necessary to read the rated values for the machine before operating it.

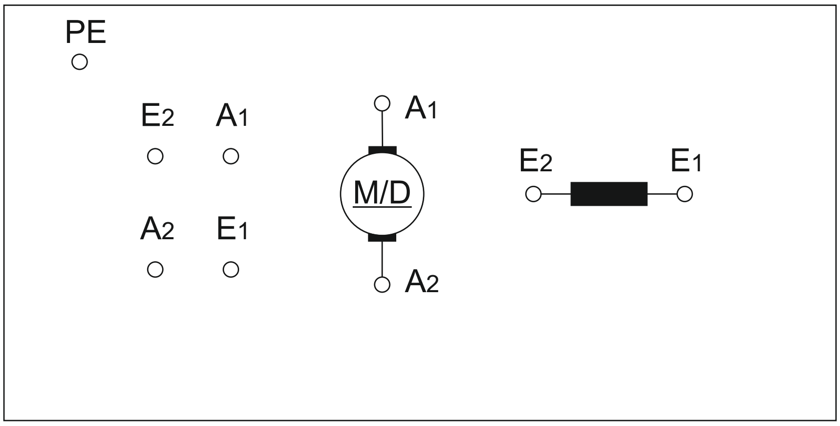

Figure-4.5 D.C shunt machine unit

Experiment 4: OPERATION OF SEPARATELY EXCITED DC SHUNT GENERATOR

Purpose : Observing the remanance voltage of the machine, analyzing the relation between the excitation Iu and the generator voltage U, obtaining the no-load characteristic curve.

Equipments :

-Experiment board with energy unit	Y-036/001
-Railed motor table	Y-036/003
-D.C shunt machine	Y-036/023-A
-Three phase asynchronous motor	Y-036/015
-Three phase asynchronous motor controller	Y-036/026
-D.C measurement unit	Y-036/006
-50 Ω 1000w rheostat	Y-036/066
-Tachometer (speedometer)	
-Jagged cable, cable with IEC plug	

Connection diagram for the experiment :

Y-036/001

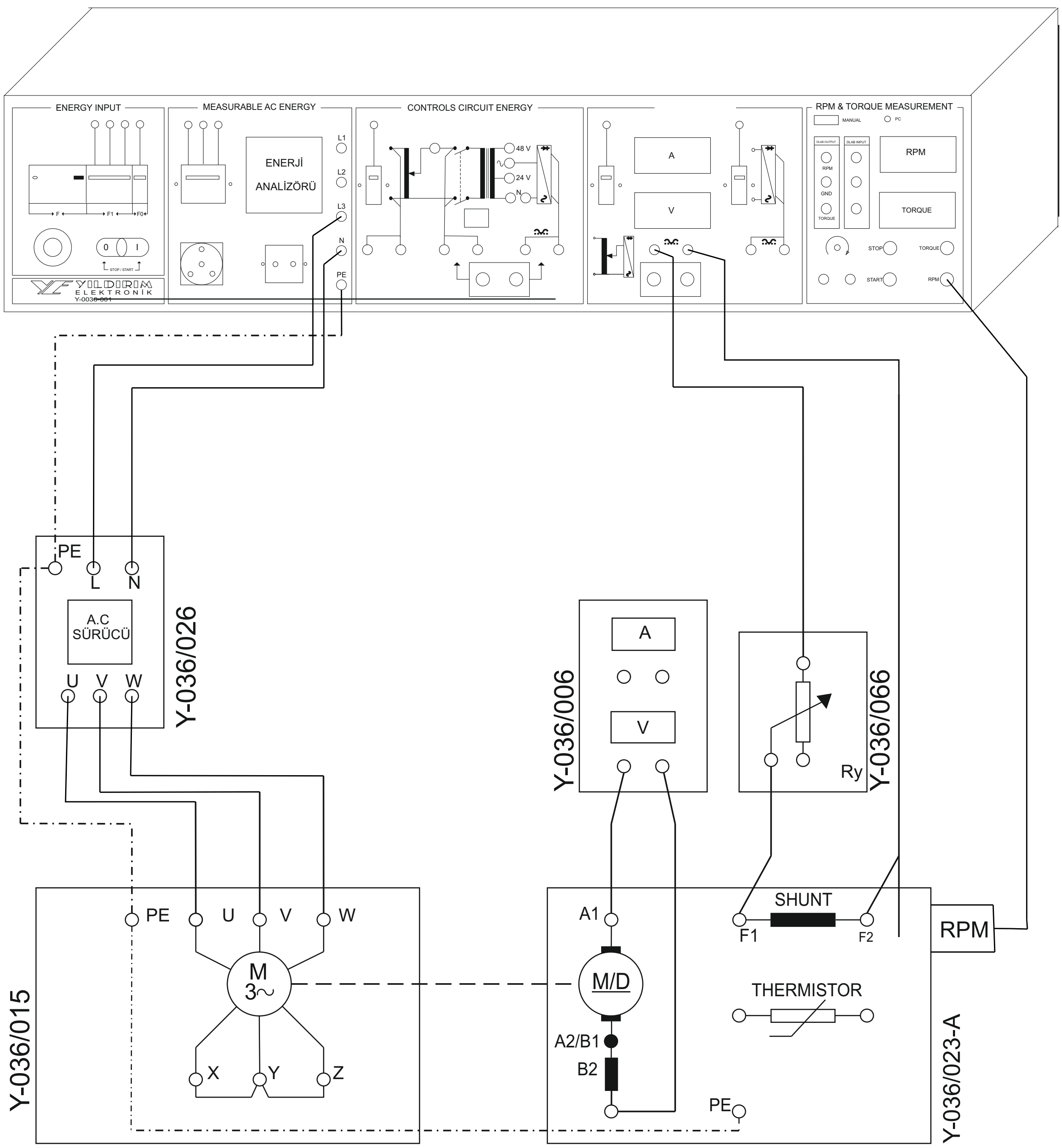

Figure 4.1: Connection diagram for the no-load operation of the separately excited DC shunt generator.

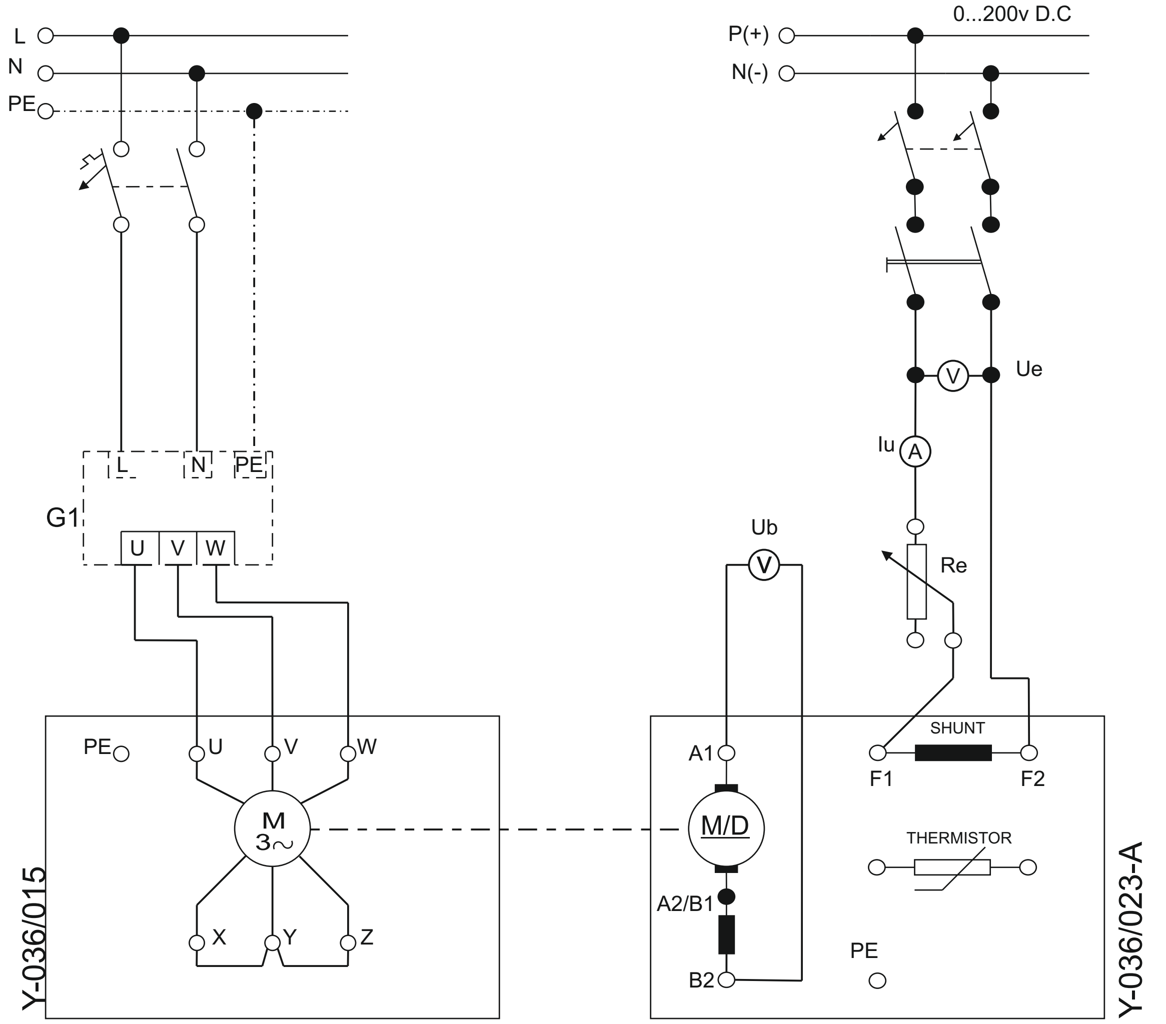

Figure 4.2: Connection diagram for the no-load operation of the separately excited DC shunt generator.

Procedure:

Not:∗Analyze the documents for the AC asynchronous motor controller. Set the speed of the motor to a value over the rated value.
* Analyze the rated values of the DC shunt machine.
*You can use a variable DC to supply the excitation circuit without using an excitation rheostat.

-Connect the circuit shown in the figure.
-Set the DC energy in the DC energy part to 200v.
-Set the speed of the motor to its rated value(1500rpm) while the excitation circuit is open and record the value of Ub.
-Apply DC energy to the excitation circuit while the excitation rheostat is at the maximum position. Take note of the values Ub-Ue-I.
-Decrease the excitation resistance step by step until the generator voltage takes its rated value (200v). Take note of the values Ub-Ue-I in each step.
-Set the generator voltage to 1.1 times the rated value using the excitation rheostat. (Vary the excitation voltage if necessary) Take note of the values Ub-Ue-I.
-Decrease the excitation current by increasing the excitation resistance step by step. Take note of the values Ub-Ue-I in each step.
-Decrease the excitation current by increasing the excitation resistance until it reaches to zero (Decrease the excitation voltage if necessary). step by step. When it reaches to zero, turn of the energy of the excitation circuit, measure and record the value of Ub.
-Turn of the energy and finish the experiment.

Values recorded in the experiment:

Speed	Ub	Ue	Iu	State
↑ n=1486 rpm constant ↓	10v	0v	0 A	
	144v	220v	0.2A	RL max 500 Ω
	157v	220v	0.3A	RL 500 Ω decreasing
	180v	220v	0.4A	RY “ “
	200v	220v	0.5A	RY 0 Ωminumum
	210v	271v	0.6A	Supply voltage is increasing.
	220v	333v	0.7A	“ “
	209v	270v	0.5A	Supply voltage is decreasing
	190v	192v	0.4A	“ “ “
	180v	193v	0.3A	RY value is increasing
	165v	193v	0.2A	“ “ “
	136v	193v	0.1A	RL “ 500Ω max
	80v	97v	0A	Supply voltage is decreasing
	10v	0v	0A	No energy in the excitation crt.

Evaluation:

Question 1: What is the voltage(Ub)measured when there is no energy in the excitation circuit?
Question 2:Is the relation between the excitation current(Ie)increase and generator voltage (Ub) increase linear? Explain the reason if not.
Question 3: Does the generator voltage increase when the excitation current increases very much? Explain.
Question 4: What is the percentage of the excitation current to its rated value when the generator voltage takes its rated value?
Question 5: How can the excitation circuit be controlled without using the resistance RL?
Question 6: State your final observations about the experiment.

Experiment 5:LOADED OPERATION OF THE SEPARATELY EXCITED DC SHUNT GENERATOR

Purpose: Operating the DC shunt generator with load; analyzing the parameters speed, load current and generator voltage; obtaining the relation between the excitation current and the volage.

Equipments:

-Experiment board with energy unit	Y-036/001
-Railed motor table	Y-036/003
-D.C shunt machine	Y-036/023-A
-Three phase asynchronous motor	Y-036/015
-Three phase asynchronous motor controller	Y-036/026
-D.C measurement unit	Y-036/006
-100 Ω 500w rheostat	Y-036/066
-2 pole switch with fuse	Y-036/052
-Tachometer (speedometer)	
-Jagged cable, cable with IEC plug	

Connection diagram for the experiment :

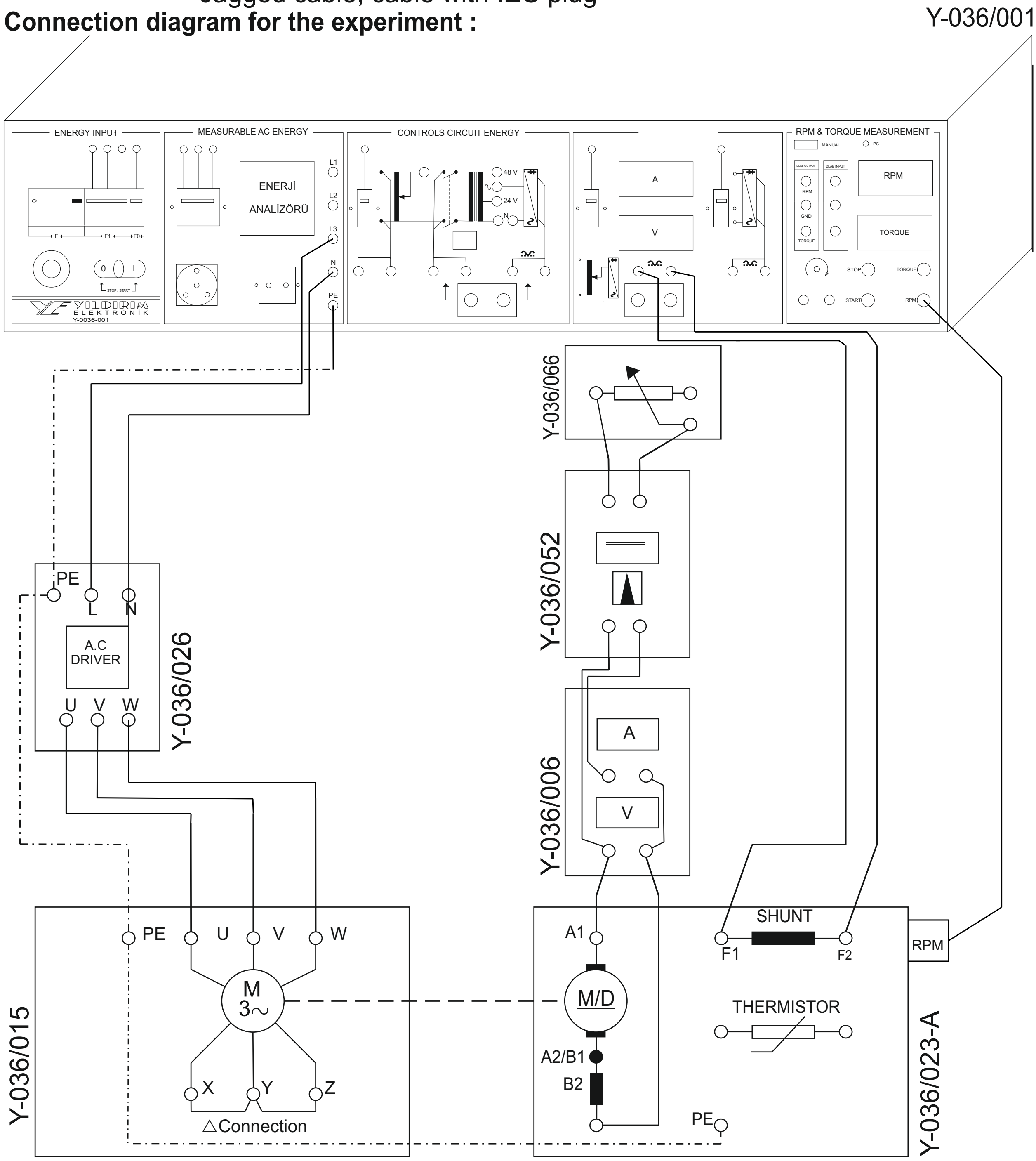

Figure 5.1:Connection diagram for the loaded operation of the separately excited DC shunt generator

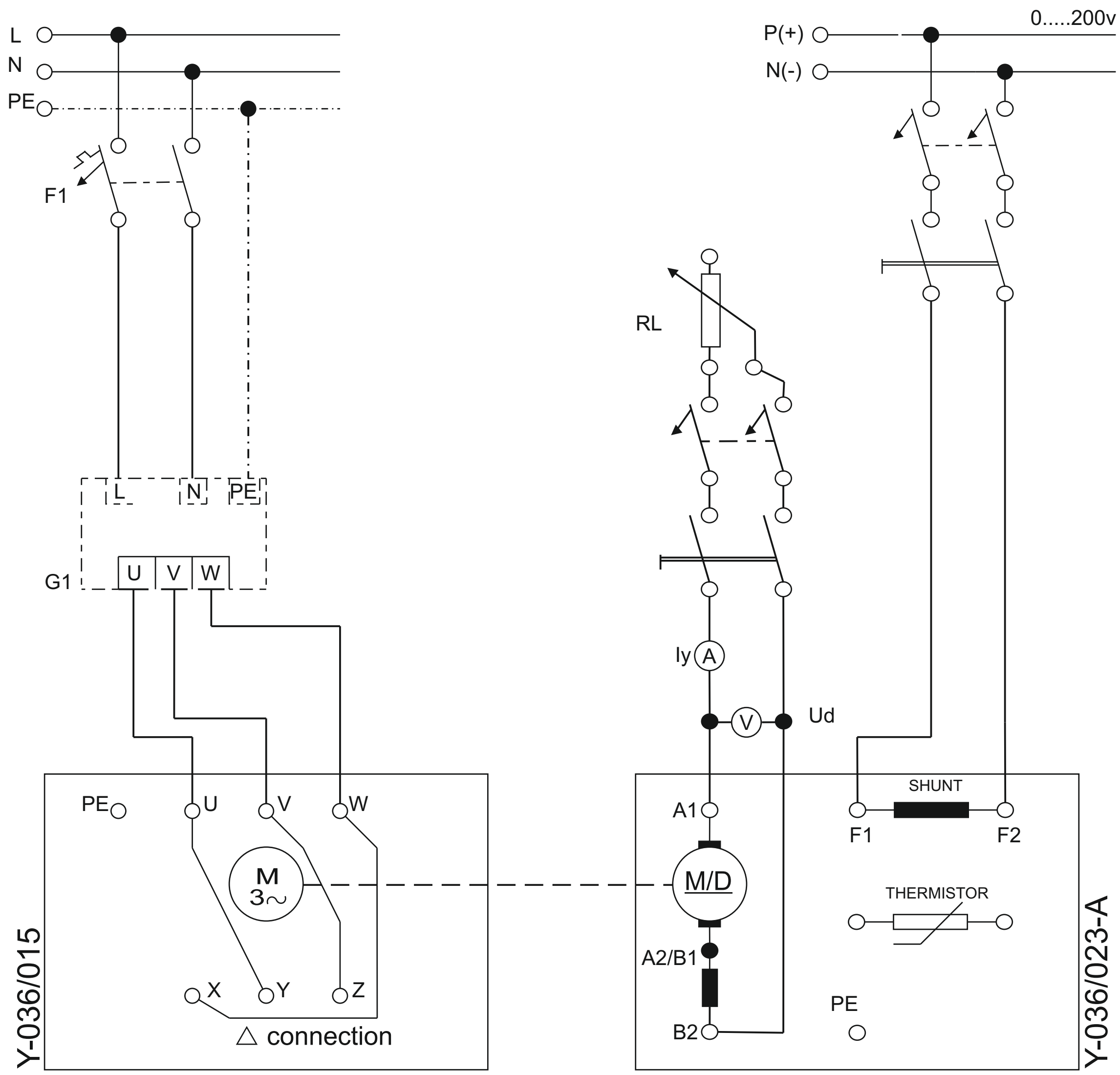

Figure 5.2:Connection diagram for the loaded operation of the separately excited DC shunt generator

Procedure:

Not:*To set the speed of the 3 phase asynchronous motor over the rated value use frequency of the AC asynchronous motor controller reading its document.
*Use Y-036/001 DC part.
*Read the label of DC machine and 3 phase asynchronous motor.

-Connect the circuit shown in the figure.
-Set the generator for rated operation using the AC driver asynchronous motor. (keep the generator at rated operation during the experiment)
-Set the excitation circuit voltage to obtain rated voltage in the generator. Take note of the values of the Ug-Ue-Ie-n.
-After turning the energy of, load the generator with rated, half of the rated, 1.2 times the rated load using the load rheostat step by step. Measure the speed an set it to rated value in each step. Record the values of Ug, IL, Ue and Ie in each step.
-Repeat the previous step without taking the speed to its rated value. Instead, vary the excitation voltage in order to keep the generator output at rated value (the excitation current should not exceed 1.2-1.3 times the rated value)
-Repeat the same step third time. In that case, keep the generator voltage at rated value keeping the speed constant and increasing the excitation voltage. Take note of the values Ug, IL, Ue, Ie and n in each step.

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-Repeat the same step for the fourth time. Load the generator up to 1.2 times the rated load. Keep the speed constant. Short circuit the terminals of the load for a short time. Take note of the values Ug, IL, Ue, Ie and n.

Values recorded in the experiment:

n	Ug	IL	Ue	Ie	Explanation

Evaluation:

Question 1: Explain the reason of the decrease in the generator voltage when it's loaded.
Question 2: Why is the speed decreased by the increasing load. Why is the current of the motor that drives the generator increased? Explain.
Question 3: Sketch the load characteristic curve of the DC shunt generator depending on the values recorded in the experiment.
Question 4: Considering the generator speed, find the voltage drop due to the armature resistance using the values recorded.
Question 5: What are the characteristic properties of DC shunt generator? Where are they used? Explain.
Question 6: State your observations about the experiment.

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Experiment 6: NO-LOAD OPERATION OF THE SELF EXCITED DC SHUNT GENERATOR

Purpose: Observing the remanance voltage at no-load operation; analyzing the relation between the excitation current (Ie) and the generator voltage (Ug), obtaining the no-load operation characteristic curve of the self excited generator.

Equipments :	-Experiment board with energy unit	Y-036/001
	-Railed motor table	Y-036/003
	-D.C shunt machine	Y-036/023-A
	-Three phase asynchronous motor	Y-036/015
	-Three phase asynchronous motor controller	Y-036/026
	-D.C measurement unit	Y-036/006
	-50 Ω 1000w rheostat	Y-036/065
	(It must be close to the field resistance)	
	-Tachometer (speedometer)	
	-Jagged cable ,cable with IEC plug	

Connection diagram for the experiment :

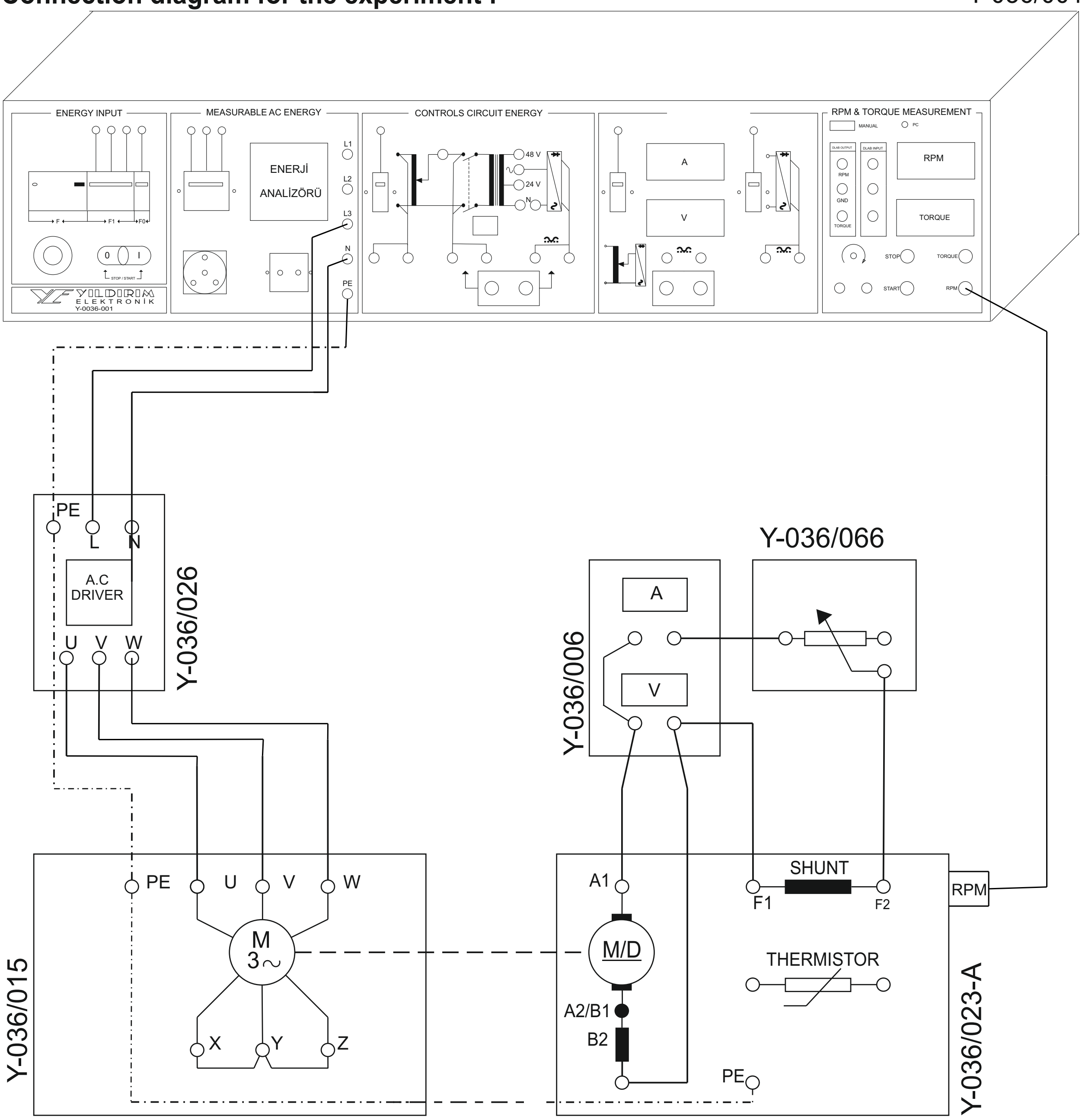

Figure 6.1: Connection diagram for no-load operation of the self excited DC shunt generator

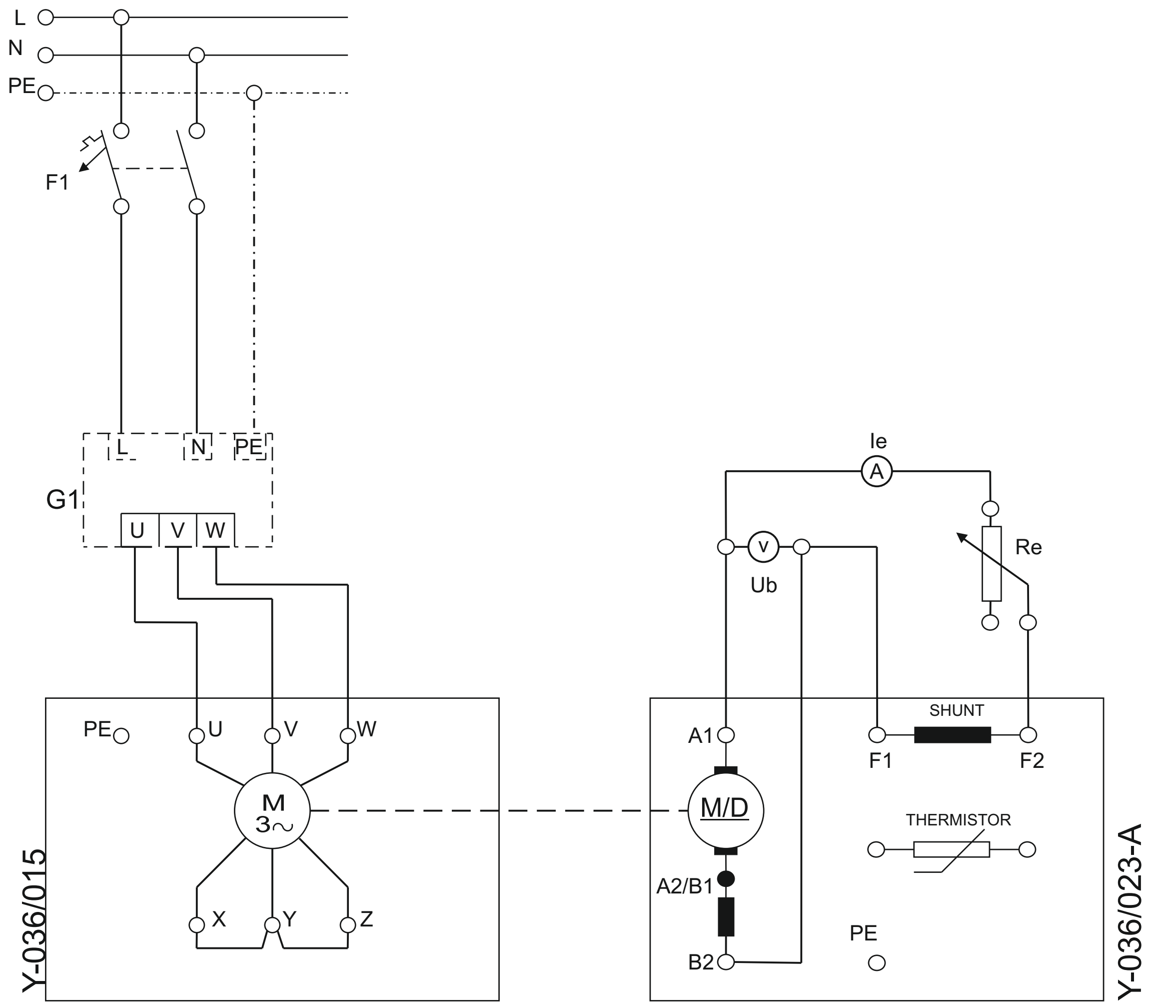

Figure 6.2: Connection diagram for no-load operation of the self excited DC shunt generator

Procedure:

Not: The value of the excitation rheostat must be close to the field resistance.

-Connect the circuit shown in figure 6.1 and figure 6.
-Set the excitation rheostat to its maximum value. The excitation circuit must be open at the beginning of the experiment.
-Set the speed of the asynchronous motor (therefore the generator) to rated value (1500 rpm) by using frequency control of the asynchronous motor controller. Measure the speed using the tachometer and record the values of n and Ug (Ie=0).
-Connect the excitation circuit while the excitation rheostat is at the maximum position. Record the values of n and Ug and Ie.
If the generator voltage (Ug) is not increased when the excitation circuit is connected, the armature must be rotating in the reverse direction. Stop the motor. Change the direction and repeat the same procedure.
-Decrease the excitation resistance till it is discarded. Record the values of n and Ug and Ie.
-Short circuit the terminals of the excitation rheostat. Measure and record the values of n and Ug and Ie.
-Turn of the energy and finish the experiment.

Values recorded in the experiment:

n rpm	Ub	Ie (Amps)	Explanation

Evaluation:

Question 1: What is the value read on the voltmeter while the excitation circuit is open?
Question 2: What is the reason of the rapid increase in the generator voltage when the excitation circuit is closed in case the excitation resistance is not changed?
Question 3: Do the excitation current(Ie) and the generator voltage (Ug) increase with the same amount? Explain the reason.
Question 4:What is the excitation current required to obtain the rated voltage at the output of the generator? What is the percentage of the generator current to its rated value?
Question 5: Sketch the no-load characteristic curve of the self excited DC shunt generator using the values recorded.
Question 6: State your final observations about the experiment.

Experiment 7: LOADED OPERATION OF THE SELF EXCITED DC SHUNT GENERATOR

Purpose: Operating the DC shunt generator with load; analyzing the relations between speed (n), load current (IL), generator voltage (U) and excitation current (Ie).

Equipments :		
	-Experiment board with energy unit	Y-036/001
	-Railed motor table	Y-036/003
	-D.C shunt machine	Y-036/023-A
	-Three phase asynchronous motor	Y-036/015
	-Three phase asynchronous motor controller	Y-036/026
	-D.C measurement unit	Y-036/006
	-50 Ω1000w rheostat (RL)	Y-036/065
	-100 Ω 500w rheostat (Re) (It must be close to the field resistance)	Y-036/066
	-2 pole switch with fuse	Y-036/052
	-Takametre (speedometer) Jagged cable ,cable with IEC plug	

Connection diagram for the experiment :

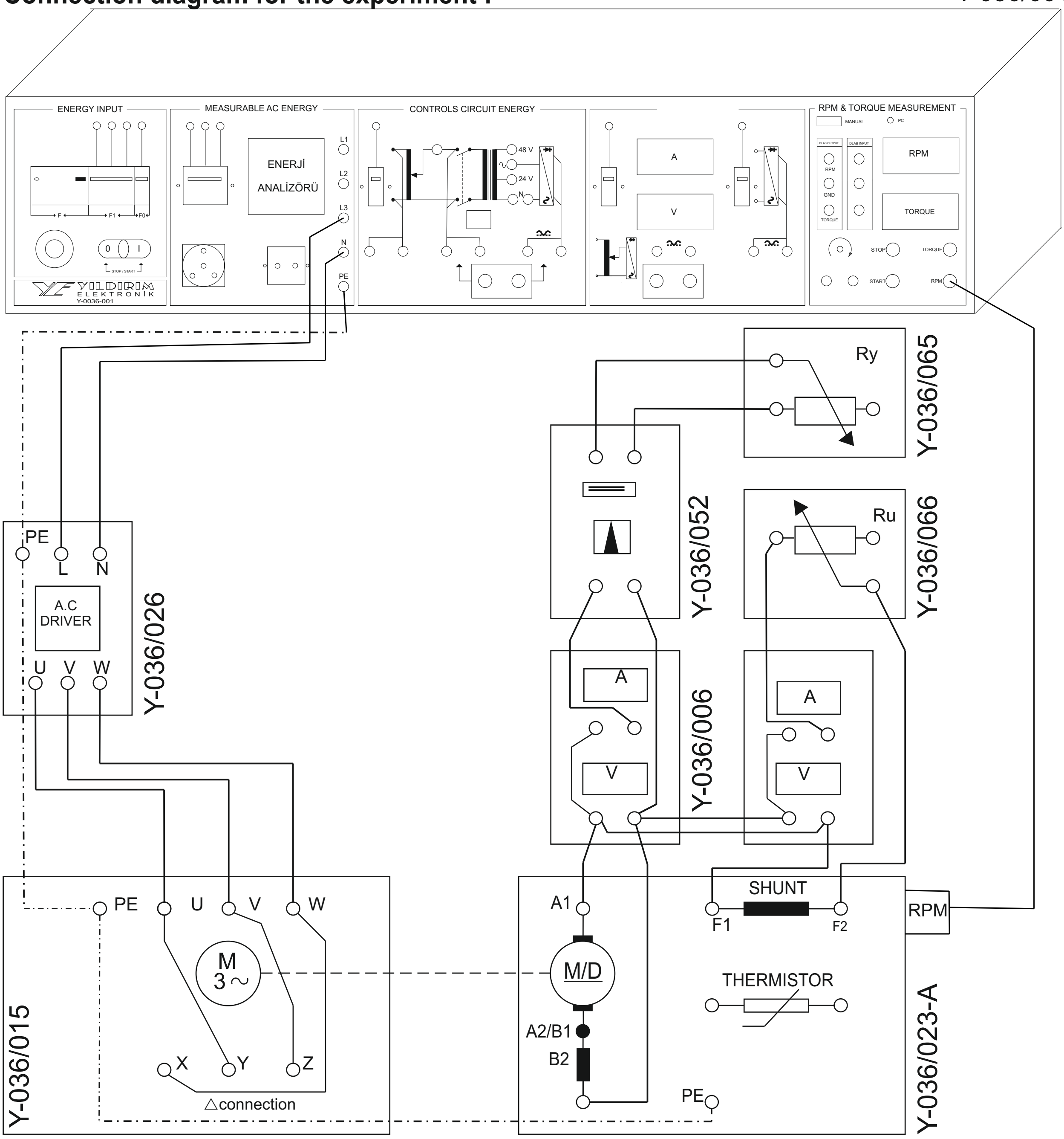

Figure7.1 Connection diagram for the loaded operation of the self excited DC shunt generator

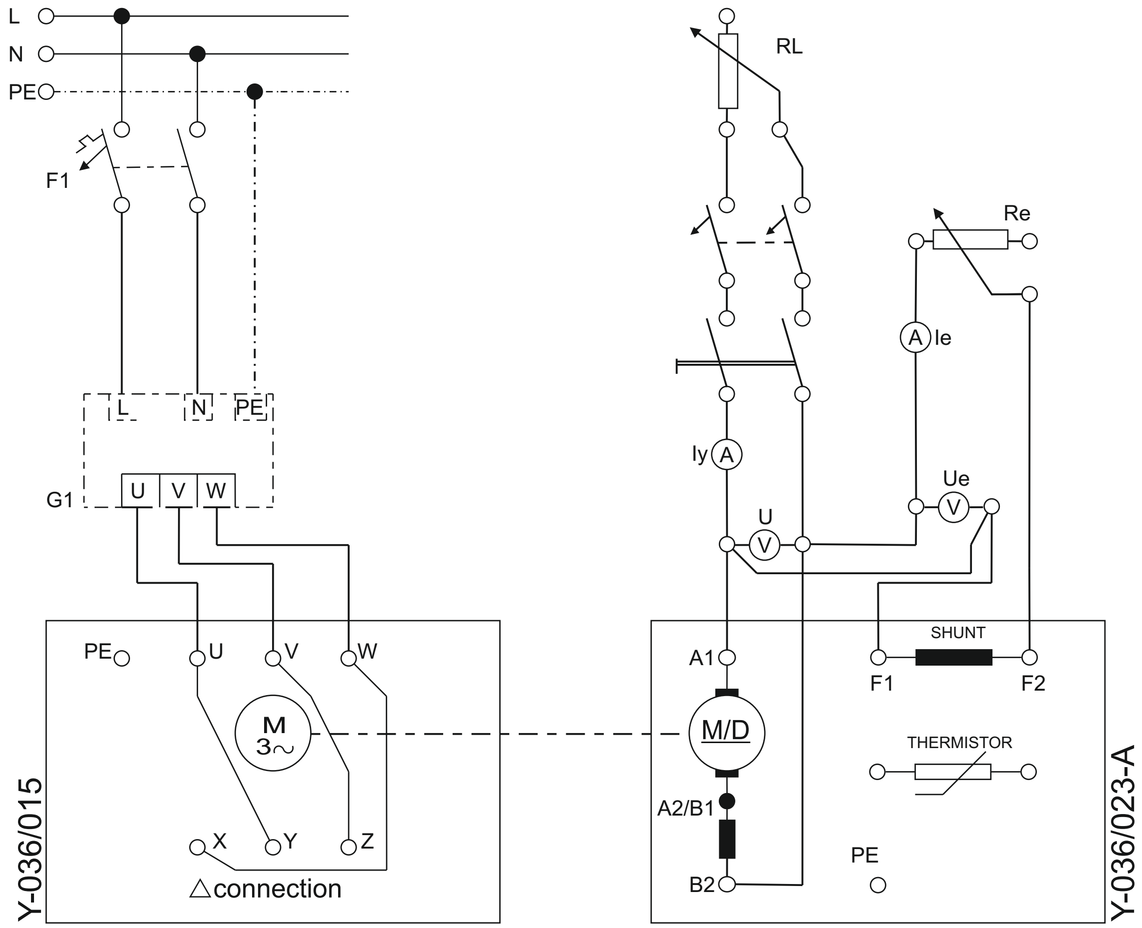

Figure7.2 Connection diagram for the loaded operation of the self excited DC shunt generator

Procedure:

Not:*Read the rated values of the three phase asynchronous motor and the DC shunt generator. Do not load them for a long time with power greater than the rated value.
*Set the frequency of the asynchronous motor controller (70Hz) in a way that the speed of the motor will be 1500 rpm when it is supplied with 1.2 times the rated power.

-Connect the circuit shown in figure 7.1.
-Set the excitation rheostat to its maximum value. Set the speed of the generator to 1500 rpm while the generator load circuit is open an try to keep that speed during the experiment.
*If the generator voltage(U) is not increased, the direction of the rotation must be inverse. Turn of the energy. Exchange two phases of the supply of the asynchronous motor. Continue the experiment.
-Increase the excitation current step by step by varying the excitation resistance. Take note of the values U, Ue, Ie and n in each step.
-Vary the excitation rheostat until the generator voltage takes its rated value. Then, take note of the values U, Ue, Ie, n and the current that the asynchronous motor pulls.
-Turn on the switch on the load circuit. Load the generator with 50% of the rated load using rheostat RL. Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
-Set the speed of the generator to its rated value (1500 rpm).Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
-Load the generator with rated load. Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
-Set the speed of the generator to its rated value (1500 rpm).Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.

-Load the generator with 1.2 times the rated load. Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
-Set the speed of the generator to its rated value (1500 rpm).Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
-Short circuit the terminals of the load for a short time. Take note of the values U, IL, Ue, Ie, n and the current that the asynchronous motor pulls.
*The current Iy will be high for a short time after the short circuit, then it will be small. The values of U, Ue and Ie may be zero. In that case take note of the values n and the current that the asynchronous motor pulls.
-Turn of the energy and finish the experiment.

Values recorded in the experiment:

Motor		Excitation		Generator		Explanation
n rpm	I(Amp)	Ue	Ie	U	IL	

Evaluation:

Question 1: Explain the reason of the decrease in the generator voltage(U) when it is loaded.
Question 2: Explain the reason of the change in the asynchronous motor current (I) and the speed (n).
Question 3: Explain the reason of the change in the values Ue and Ie in the excitation circuit when the generator is loaded.
Question 4: What happened when the shunt generator is short circuited? Explain that case considering the values recorded.
Question 5: Sketch the load characteristic curve of the DC shunt generator according to the values recorded.
Question 6: State your final observations about the experiment.