MPPT ALGORITHMS ON PHOTOVOLTAIC SYSTEMS AND THEIR COMPARISONS

FOTOVOLTAİK SİSTEMLERDE MGNİ ALGORİTMALARI VE KARŞILAŞTIRMALARI

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ABSTRACT

Solar cells, which are the most important elements of photovoltaic (PV) systems, have the feature that determines the initial cost and the quantity and quality of other elements that we will use in the solar panel system. For this reason, we must design the system we will install by making sure that the solar cells will operate at the highest efficiency and in the best conditions. The maximum power point at which solar systems operate depends on the angle of the sun rays to the panel surface and the temperature of the existing panels. For this reason, we cannot say that every working load in the system is the maximum power point of the photovoltaic system. The number of modules is increased to provide the demanded power of a PV system operating at a constantly changing power. This increases our cost and causes us to lose energy. We use a maximum power point tracker (MPPT) to solve this problem. Thus, we ensure that photovoltaic systems operate continuously at the maximum power point. In this paper, we will explain different MPPT algorithms and their comparisons.

Keywords: *MPPT, MPPT Algorithms, Solar Energy, PV systems*

ÖZ

Fotovoltaik (PV) sistemlerinin en önemli elemanı olan güneş pilleri, ilk maliyeti ve güneş paneli sisteminde kullanacağımız diğer elemanların miktarlarını ve niteliğini belirleyen özelliğe sahiptir. Bu sebeple kuracağımız sistemi, güneş pillerinin en yüksek verimlilikte ve en iyi şartlarda çalışacağından emin olarak tasarlamalıyız. Güneş sistemlerinin çalıştığı maksimum güç noktası ise güneş ışınlarının panel yüzeyine yaptığı açıya ve mevcut olan panellerin sıcaklığına bağlıdır. Bu nedenle ise sistemdeki her çalışma yüküne, fotovoltaik sistemin maksimum güç noktası diyemeyiz. Sürekli değişen güçte çalışan bir PV sisteminin, talep edilen gücü sağlaması için ise modül sayısı arttırılır. Bu ise maliyetimizi arttırır ve bize enerji kaybı yaşatır. Bu sorunu çözmek için maksimum güç noktası izcisi (MGNİ) kullanıyoruz. Böylece fotovoltaik sistemlerin maksimum güç noktasında sürekli olarak çalışmasını sağlıyoruz. Bu yazımızda ise farklı MGNİ algoritmalarını ve onların karşılaştırmalarını anlatacağız.

Anahtar Kelimeler: *MGNİ, MGNİ Algoritmaları, Güneş Enerjisi, PV sistemleri*

1. INTRODUCTION

A photovoltaic system, or PV system is a system that converts solar energy into usable energy. The PV system is created by combining many components and absorbs sunlight with solar panels and converts it into electricity. The solar inverter changes the electrical current from direct current to alternating current. As such, splicing, wiring, and the installation of other electrical appliances form a working system.

This paper focuses on MPPT algorithms and their comparisons. System elements of PV will be mentioned in title 2. Advantages and disadvantages of PV energy will be mentioned in title 3. Factors affecting efficiency in electricity generation from solar energy will be mentioned in title 4. Finally, MPPT algorithms and their comparisons will be mentioned in title 5.

2. SYSTEM ELEMENTS OF PV

A. Solar Panel

The most crucial component of a solar energy system is the solar panel. The solar panel collects the sun's rays, which are then turned into electrical energy. The solar panel is made up of conductive silicon solar cells. The sun rays collected on the panel are collected in the solar cells and create direct current. Thanks to the conductive structure, electron flow occurs and electrical energy is released. As the number of solar panels increases, energy emissions also increase.

Solar energy panels are installed in areas with sufficient sunlight. It is very important how long the area where the panels will be installed receives the sun at the right angle, the length of the summer season, and the fact that the winter season does not pass under harsh conditions will increase the efficiency to be obtained from the solar energy system.

B. Battery

After the panels, the most important part of the solar energy system is the battery. Also known as a solar cell or a solar battery. Thanks to the battery, the electrical energy produced by the panels is stored for later use. When the weather is cloudy and the sunlight cannot be used to meet an instant need, the electrical energy stored by the battery is easily used. Since electrical energy cannot be produced from sunlight at any time, the use of batteries is a necessity in the solar energy system. Solar batteries are low-cost and maintenance-free.

The charging circuits and the charger are the two most important parts of the solar battery. Thanks to these parts, the battery can function to store electricity. The charging circuits convert the electrical energy obtained from the sun into a suitable form and store it in the battery. Choosing the charging circuits at a level that will reach an average threshold level in accordance with the summer and winter seasons when the intensity of the sun's rays changes is very important for the proper functioning of the battery. Otherwise, electricity may not be stored due to solar energy that cannot exceed a certain threshold level in winter. This reduces the efficiency of the solar energy system.

The main features of the batteries used in solar energy systems are as follows:

- Solar batteries are designed to have a long service life.
- It has a higher energy density compared to normal batteries, and is capable of storing solar energy.
- It can withstand both hot and cold conditions.
- When the battery is not used, the risk of discharge is very low.
- The materials that make up the battery are resistant to wear.

C. Inverter

The inverter is a very important component of the solar panel. Thanks to the inverter, the electrical energy in direct current produced in the panels is converted into alternating current and made suitable for use. The inverter to be used in solar energy systems should be selected according to the size of the panels. Since more electrical energy will be produced if the panels are large and many, the inverter should be selected with a high capacity in direct proportion to this. Thanks to the inverter, electrical energy of suitable power can be provided to all devices that need electricity. The most preferred inverter type is the inverter used in electricity distribution networks, which is a full-sine inverter.

D. Battery Regulator

It is a device that prevents the battery from being fully discharged and charged to full capacity in the same way. Thanks to the battery regulator, the battery functions with optimum efficiency. The use of a battery regulator extends the life of the battery.

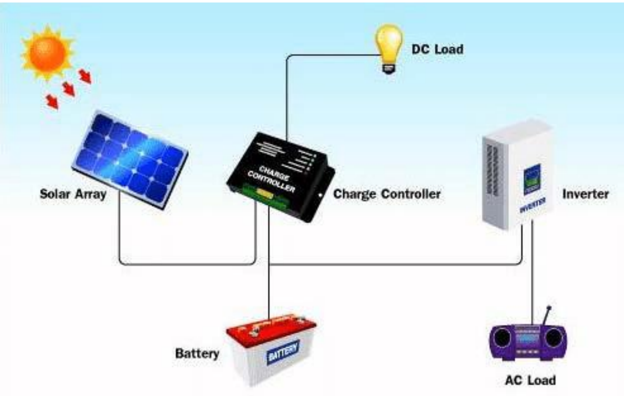

Figure 2.1 – System Elements of PV[1]

3. ADVANTAGES AND DISADVANTAGES OF PV

A. Advantages

- The lifetime of PV systems is long enough to amortize their cost.
- They are easy to maintain and the maintenance costs are very low.
- There are no fuel purchases or transportation costs because it runs on solar energy. In addition, since it is not dependent on the fuel market, it is not affected by cost changes.
- They do not leave any harmful waste to the environment and work silently.
- Since it has no moving parts, it malfunctions less than a generator. If a module or battery in a medium-sized system fails, the entire system is not affected and continues to operate.
- Although the initial investment cost is high compared to generators, it is less costly in long-term use due to fuel and maintenance costs.
- In PV systems, installation and cabling operations do not have to comply with electrical laws, so their costs are low.
- The system gives the opportunity to be dismantled and removed if desired.

A. Disadvantages

- The initial investment cost is high.
- They are not cost-effective for high-capacity engines or heating systems.
- The rate of converting solar energy into electricity is low, so it needs large areas.
- The production potential of the system is affected by seasonal and daily weather changes.
- Since they produce direct current, the electricity produced must be converted to alternating current in order to be suitable for use.

4. FACTORS AFFECTING EFFICIENCY IN ELECTRICITY GENERATION FROM SOLAR ENERGY

A. Radiation Losses

It is related to the angle at which the panel is placed. The more solar radiation comes to the photovoltaic panel, the more energy the panel will produce. Minimizing the losses that may occur in the radiation value of the panel will ensure the formation of an efficient solar energy system.

A.1. Spectrum Losses

They are the losses caused by the deviations of the solar radiation on the earth's surface until it reaches the panel.

A.2. Reflection Losses

Some of the radiation coming to the panel is reflected back from the panel surface without being absorbed by the cells inside the panel. These are the losses caused by the reflection of the radiation on the panel before it reaches the cell. In order to prevent this reflection in photovoltaic panels, it is ensured that the reflection is minimized by using anti-reflection coatings. According to the data obtained under normal radiation conditions, the panels reflect 4% of the incident light.

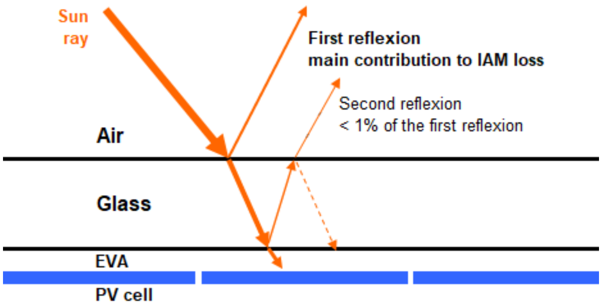

Figure 4.1 – Schematic Illusturation of Reflection Loss[2]

A.3. Shading Losses

The voltage difference between the shaded parts of the panels in solar power plants and the parts that are not shaded creates shading losses.

Figure 4.2 – Real Life Example of Shading Losses[3]

A.4. Horizon Shading

It is the shading caused by factors such as mountains and hills in the area where the power plant is installed. Horizon shading is generally uniform at all points of the plant.

A.5. Panel Row Shading

The shading of the panels in the switchboards against each other is called panel row shading.

A.6. Dusting and Blasting Losses

Due to the contamination of the surfaces of the panels, the amount of solar radiation coming to the panels decreases. For this reason, this effect is called the pollination effect. In this case, it is necessary to clean the panel surfaces at a level that can receive sufficient solar radiation. Losses due to snowfall are evaluated under this effect.

B. System Losses

There are parameters to be considered while designing solar power plants. There are losses due to these design parameters.

B.1. Low Radiation Losses

It is the losses seen in the power outputs of solar energy panels due to low radiation at different irradiance values.

B.2. Temperature Losses

There is an inverse relationship between the photovoltaic panel power output and the panel temperature. As the panel temperature rises, the received power decreases. The losses caused by the temperature are directly proportional to the cell temperature. If the ambient temperature where the panels are located increases, the cell temperature also increases, so the energy produced by the panels decreases.

B.3. Losses of Non-Compliance

Environmental stress is related to damage to panels due to weather conditions. The fact that the panels in a photovoltaic panel array are at different operating temperatures or are exposed to different radiation values and angles can be characterized as incompatibility loss.

B.4. Cable Losses

Cable losses are due to ohmic losses in DC and AC cables used in photovoltaic systems.

C. Inverter Losses

Inverter losses are calculated by means of the inverter efficiency curve, taking into account the energy consumption of the inverter in standby mode.

Metrics such as European Efficiency and Weighted Efficiency are used for DC/AC power cycle efficiency. DC/AC loop losses in the inverter depend on the type of power layer topology and the operational characteristics of the semiconductor, magnetic elements and capacitors used in the PV inverter, such as conduction and switching.

Typically, PV inverter efficiency decreases by 0.3% to 1% per 150 V DC input voltage amplitude. In addition, the efficiency decreases by up to 5% at low irradiance and high DC input voltages due to the power consumption of the control unit and switching losses.

5. MPPT ALGORITHMS AND THEIR COMPARISONS

A. P&O Algorithm

The P&Q algorithm is the most commonly used approach in practice due to its simplicity in implementation. In this algorithm, the P-V characteristic of the photovoltaic panel is used. As is known, the power produced from photovoltaic panels varies as a function of voltage. In the error and observation algorithm, a small increase in the operating voltage of the PV panel is performed, and the amount of change in power ΔP is measured. If the ΔP value is positive, the operating voltage is increased again, bringing the PV panel operating point closer to the maximum power point. Thus, small errors are created in the voltage and the sign of the error occurring in the power is followed.

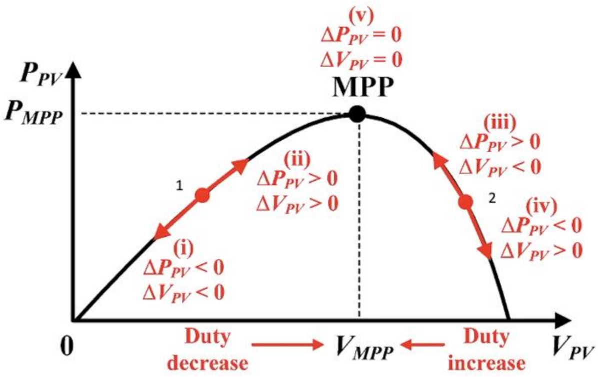

Figure 5.1 – P-V Characteristic

In the first region, ΔP = Instantaneous Power - Previous Power and ΔV = Instantaneous Voltage - Previous Voltage are less than zero. Therefore, we need to decrease duty cycle. It means voltage should be increased.

In the second region, ΔP = Instantaneous Power - Previous Power and ΔV = Instantaneous Voltage - Previous Voltage are greater than zero. Therefore, we need to decrease duty cycle. It means voltage should be increased.

In the third region, ΔP = Instantaneous Power - Previous Power is greater than zero and ΔV = Instantaneous Voltage - Previous Voltage is less than zero. Therefore, we need to increase duty cycle. It means voltage should be decreased.

In the fourth region, ΔP = Instantaneous Power - Previous Power is less than zero and ΔV = Instantaneous Voltage - Previous Voltage is greater than zero. Therefore, we need to increase duty cycle. It means voltage should be decreased.

The fifth region is the maximum power point (desired power).

We wrote the code for the P&O algorithm in C.

```
float Pprevious, Vprevious,
Dprevious; // These are previous
values (threshold)
float Ppv, Vpv, Ipv; // These are new
values that are scanned
float deltaD = 110e-6; // One unit
increasing of duty cycle
```

```
float DutyCycle = 2000.0; // Duty
Cycle for updating

float scanVoltage(){
  printf("Scanning for
Voltage...\n");
  scanf("%f",&Vpv);
  return Vpv;
}

float calculatePower()
{
  printf("Scanning for
Current...\n");
  scanf("%f",&Ipv);
  Ppv = Ipv*Vpv;
  return Ppv;
}

void pAndqAlgorithm()
{
  if((Ppv-Pprevious) != 0){
    if((Ppv-Pprevious) > 0){
      if((Vpv-Vprevious) > 0){
        DutyCycle = Dprevious -
deltaD;
        printf("Duty Cycle
decreased.\n");
      }
      else{
        DutyCycle = Dprevious +
deltaD;
        printf("Duty Cycle
increased.\n");
      }
    }
    else{
      if((Vpv-Vprevious) > 0){
        DutyCycle = Dprevious +
deltaD;
        printf("Duty Cycle
increased.\n");
      }
      else{
        DutyCycle = Dprevious -
deltaD;
        printf("Duty Cycle
decreased.\n");
      }
    }
  }
}

int main()
{
  Vprevious = scanVoltage();
  Pprevious = calculatePower();
  while(1){
    Vpv = scanVoltage();
    Ppv = calculatePower();
    pAndqAlgorithm();
    Vprevious = Vpv;
    Pprevious = Ppv;
  }}
```

The flowchart for this code is shown below.

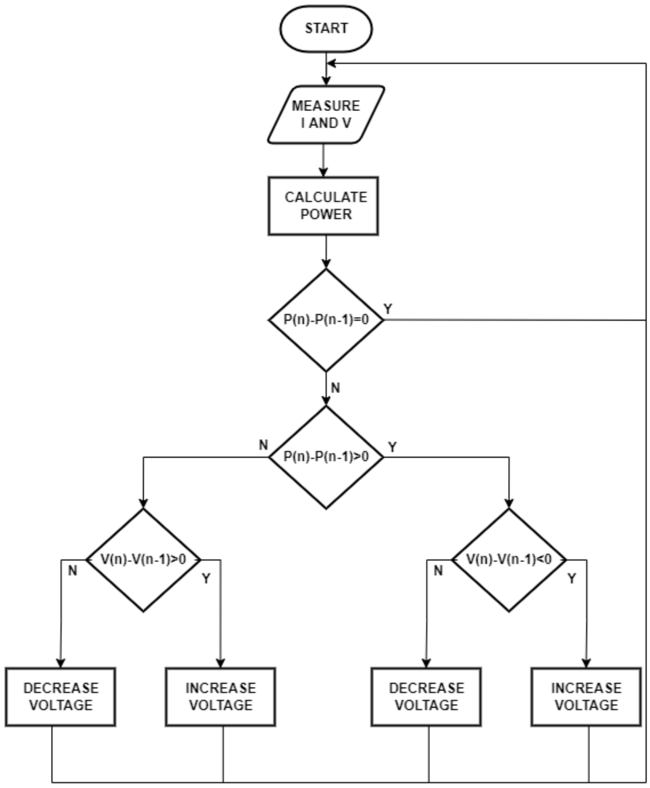

Figure 5.2 – Flowchart of the P&O Algorithm

B. Incremental Conductance Algorithm

The incremental conductance algorithm is based on the principle of taking the derivative of the photovoltaic panel power according to the voltage and equalizing it to zero. Accordingly, at the maximum power point,

$\frac{dP}{dV} = \frac{d(V \times I)}{dV} = I + V\frac{dI}{dV} = 0$. Rearranging the equation yields $-\frac{I}{V} = \frac{dI}{dV}$. The expression $-\frac{I}{V}$ expresses the inverse of the instantaneous conductivity value of the photovoltaic panel. The expression on the right side of the equation is the increasing conductivity value. In this case, at the maximum power point, these two values should be equal to each other but with opposite signs. If this equation is an inequality, it is understood that the operating voltage is lower or higher than the MPP voltage.

The incremental conductance method, unlike the P&O methods, can calculate in which direction a voltage change should be made. It can also detect whether the maximum power point has been fully reached. Thus, even under rapidly changing conditions, they do not oscillate around the MPP due to misdirection tracking.

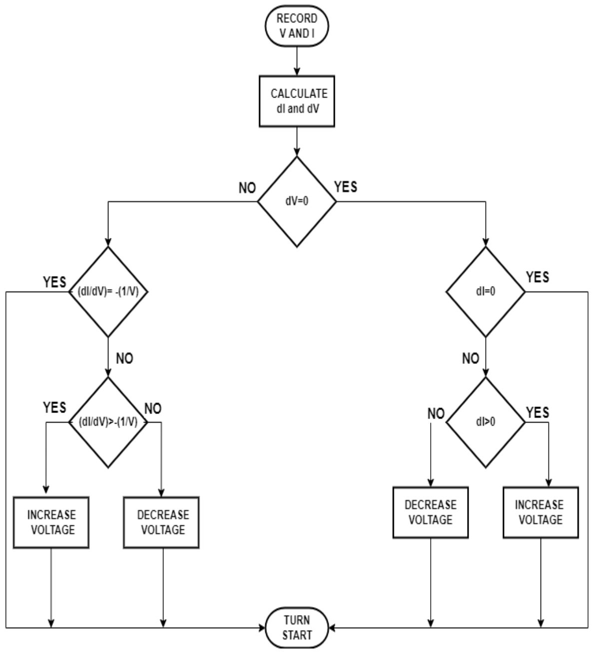

Figure 5.3 – Flowchart of the Inceremental Conductance Algorithm

C. Constant Voltage and Current Algorithm

The constant voltage (CV) algorithm is based on the principle that the ratio between the voltage at the maximum power point and the open circuit voltage is approximately constant.

In the CV algorithm, the solar panel is temporarily separated from the MPPT, the open circuit voltage is measured, and the MPP voltage is calculated. By adjusting the panel voltage to this calculated value, operation in MPP is ensured. This process is repeated periodically, and the position of the MPP is constantly monitored. Although this method is quite simple, it is difficult to determine the optimal value of the constant K. It has been revealed in the literature that the K value varies between 73 and 80%.

Constant voltage control can be easily realized with analog equipment. However, the MPP tracking efficiency of this method is lower than other algorithms. The reason for this is the difficulty of obtaining the optimal value of the K constant mentioned before, and more importantly, it requires a sudden cut-off of the PV power in order to measure the open circuit voltage.

The approach mentioned above for the constant voltage algorithm can be applied to constant current (CC) in the same way. In the constant current algorithm, the process is done by controlling the ratio between the current at the maximum operating point and the short-circuit current. To perform this method, a switch placed at the PV panel output or converter input is used. This switch is closed instantly and the short circuit current value is measured. The voltage at the operating point is determined by using the K constant. This process is repeated periodically.

Naturally, the constant voltage method is preferred. Because measuring voltage is easier than measuring current. Also, turning the panel into an open circuit is a simple process. Short-circuiting the panel terminals may not be practical most of the time.

5. CONCLUSION

There are several algorithms for MPPT. We have mentioned just three of them. The algorithms that we have chosen are more understandable and clearer than others. In PV systems, power can not always be at its maximum due to some losses. These losses cause less efficiency in the system. Therefore, tracking the power can be helpful to keep the system running at high efficiency. The P&O algorithm, which is the simplest one, keeps records of voltage and power. Then it compares the instantaneous value with the previous value. Based on the conditions, it changes the duty cycle. It means changing the voltage of the system. The incremental conductance algorithm is based on the principle of taking the derivative of the photovoltaic panel power according to the voltage and equalizing it to zero. If the equation is an inequality, it is understood that the operating voltage is lower or higher than the MPP voltage. The incremental conductance method, unlike the P&O methods, can calculate in which direction a voltage change should be made. It can also detect whether the maximum power point has been fully reached. Thus, even under rapidly changing conditions, they do not oscillate around the MPP due to misdirection tracking. It is a bit more complicated compared to the P%O algorithm. The constant voltage (CV) algorithm is based on the principle that the ratio between the voltage at the maximum power point and the open circuit voltage is approximately constant. There are two methods, which are the constant voltage method and the constant current method. The constant voltage method is preferred. Because measuring voltage is easier than measuring current. Also, turning the panel into an open circuit is a simple process. Short-circuiting the panel terminals may not be practical most of the time.

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