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Dynamic Price Control Using Pole Placement Method in Smart Grids

Akilli Şebekelerde Kutup Yerleştirme Metodu Kullanarak Dinamik Fiyat Kontrolü

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Özetçe— Enerji, çağlar boyunca insanoğlu için en temel gereksinimlerinin başında gelip; ulaşım, ısınma ve aydınlanmadan turizm sektörüne kadar birçok kullanım alanıyla hayatımızdan çıkaramayacağımız en önemli kavramlardan biri olmuştur. Yenilenebilir enerji ise nüfusun artmasına göre azalmayan, yeryüzünde doğal olarak elde edilebilen, enerji yetersizliği ve birtakım problemlere alternatif çözüm oluşturabilecek kaynaklardır. Yenilenebilir enerji kaynaklarının kullanımı için avantaj sağlayan akıllı şebeke kavramı gelecekte enerjinin aralıklı üretim ve anlık olarak değişen talep koşulları altında enerji ağının kontrol edilebilir olmasını sağlamaktadır. Akıllı şebekelerde dağıtık üretimin de artmasıyla birlikte üretim ve tüketim koşulları enerji fiyatlandırmasının dinamik bir yapıda olmasının önünü açmıştır. Bu çalışmada akıllı şebekelerde otonom kontrolü sağlanabilen ve güvenli bir şekilde enerji elde etme yöntemlerinden biri olan, dinamik elektrik fiyatlandırması yapılarak fiyat dengelenmesi sağlanmıştır. Bu amaçla kutup yerleştirme metodu kullanılarak elde edilen Oransal-İntegral-Türev (PID) kontrolörün katsayıları enerji arz-talep senaryosu ile MATLAB/SIMULINK ortamında modellenmiştir. Enerji talebinin değişiminin fiyat üzerindeki etkisinin incelenmesi için enerji talebine anlık olarak zirve ve düşüş verilmiştir. Değişen talep koşullarına göre PID kontrolörün fiyat dengesini sağladığı, enerji fiyatını çevrimiçi olarak düzenlediği ve enerji dengesini koruduğu görülmüştür.

Anahtar Kelimeler: Enerji Dengesi, PID Kontrol, Kutup Yerleştirme Metodu, Dinamik Enerji Fiyatlandırma, Talep Taraflı Stratejik Yöntem.

Abstract— Energy has been one of the most important concepts that we cannot remove from our lives with its many uses, from transportation, warming, and enlightenment to the tourism sector, being at the beginning of the most basic requirements for humanity for centuries. Renewable energy is a resource that does not decrease according to the increase of the population, can be obtained naturally on earth, can create an alternative solution to energy shortages and several problems. The concept of a smart grid, which provides an advantage for the use of renewable energy sources, ensures that the energy network can be controlled in the future under conditions of intermittent energy production and instantaneous demand. With the increase in distributed production in smart grids, production and consumption conditions have paved the way for energy pricing to be dynamic. In this study, price balancing was achieved by dynamic electricity pricing, which is one of the methods of achieving autonomous control in smart grids and obtaining energy safely. For this purpose, the coefficients of the Proportional-

Integral-Derivative (PID) controller obtained using the pole placement method are modeled in the MATLAB/SIMULINK program with the energy supply-demand scenario. In order to examine the effect of change in energy demand on price, a temporary peak and fall are given to energy demand. According to changing demand conditions, the PID controller has been shown to provide price balance, regulate energy price online and maintain energy balance.
Keywords : *Energy Balance, PID Control, Pole Placement Method, Dynamic Energy Pricing, Demand-Side Strategic Method.*

1. Introduction

Due to the rapid growth of the world's population and the increasing energy demand of people in proportion to this, smart grid applications have become one of the most effective fields today. Increasing the need for energy due to increasing energy demands has raised issues of energy efficiency and management. Classical networks are electricity distribution systems in which control systems are not used, which allow the generated electricity to be transmitted by increasing the voltage level, then gradually reducing the voltage levels to the required levels and transmitted to the end consumer. Smart grids, in its most general definition, are the addition of control systems and smart meters to the classical grid in order to ensure full automation between the manufacturer and the user. Smart grids prioritize security, which enable instantaneous monitoring and updating of the grid, and enable the user to actively participate in the grid as a productive consumer [1]. The following reasons can be listed as one of the most important factors in the emergence of smart energy systems. These are the reasons such as the increased need for energy in daily life, the lack of efficient energy consumption and the damages of environmental factors, the rapid increase in population and the gradual decrease in fossil fuels [2, 3]. If the infrastructure of smart grid systems is defined as the addition of artificial intelligence and algorithms in addition to infrastructure materials such as silicon and fiber to classic grid systems, a representative drawing of this is shown in Figure-1.

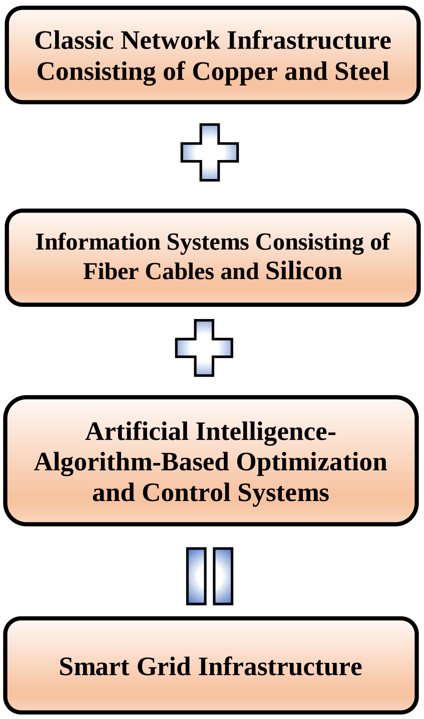


Figure 1. Smart Grid Infrastructure Layers

It is very important that these systems are can communicate and observable when considering applications for smart grids. For this, smart meters are used, which provide bi-directional production and consumption data in data transmission systems. In short, data communication is used today with smart meter applications [4].

The most important advantage of smart grid systems is that renewable energy sources are included in the system. In the future, electricity generation will be based on more renewable sources due to rising energy prices, carbon dioxide emissions, and the greenhouse effect [5-10]. The use of these resources includes the consumer into the network as a productive consumer. The use of renewable energy sources plays a major role in reducing energy prices by reducing energy demand due to their dependence on the grid, that is, the fact that consumers have productive adjectives. Dynamic pricing will provide flexibility in demand along with energy supply in smart grid systems. It has been observed that this situation provides energy stability autonomously with closed-loop price regulation. In addition, it has allowed the use of renewable resources such as sun and wind, which cause intermittent energy production [10-13].

In this study, real-time dynamic energy pricing in smart grids was optimized by designing PID controller. The coefficients of the PID controller designed for this purpose were found using the pole placement method and the effects of changes in the natural frequency and damping ratio on the system were studied. The analyses were confirmed in MATLAB / SIMULINK package program.

2. Material and Method

2.1. PID Controller

PID controllers are the most used controller structure for industrial purposes, and the parameter values of this controller are obtained both experimentally and analytically. There are many methods in the literature to find the PID controller coefficients. The most widely used of these methods are Ziegler-Nichols and Cohen-Coon methods. Controller coefficients obtained mathematically by these methods can be trained using optimization methods and artificial neural networks. Similarly, these methods allow us to find the controller coefficients using frequency and time domain responses [14].

PID controller control the system through a continuous feedback signal in order to minimize the error signal in the system by comparing the signal called the start or reference signal at the input with the feedback signal at the system output [15].

In a study that makes price control using a PID controller, the PID controller regulates the energy price by providing the balance error signal between supply and demand. Virtual demand has been added to the system to generate more profits by involving the producer community in the network. In the system, production was kept higher than demand. The PID controller regulated the price by responding instantly to the variable demands of the consumers in the network. PID coefficients were adjusted randomly and the price response was taken instantly and it was seen that the PID controller provided the system balance [10].

2.2. Pole Placement Method

The pole placement method is one of the basic design methods. By placing the poles at the desired location, the system can be calculated according to certain criteria as desired. In this study, the location of the poles was changed depending on the natural frequency (ω_n) value, resulting in system oscillation and price optimization.

2.3. Equilibrium Price on Supply-Demand Graph

The basis of dynamic energy pricing that enables electricity generation is based on demand-side management strategies. Every transaction that consumers take to benefit the grid can be called demand-side management (DSM). These processes can be listed as follows; load shifting, valley filling, peak clipping, strategic demand growth and strategic conservation [16]. These strategies are given in Figure 2.

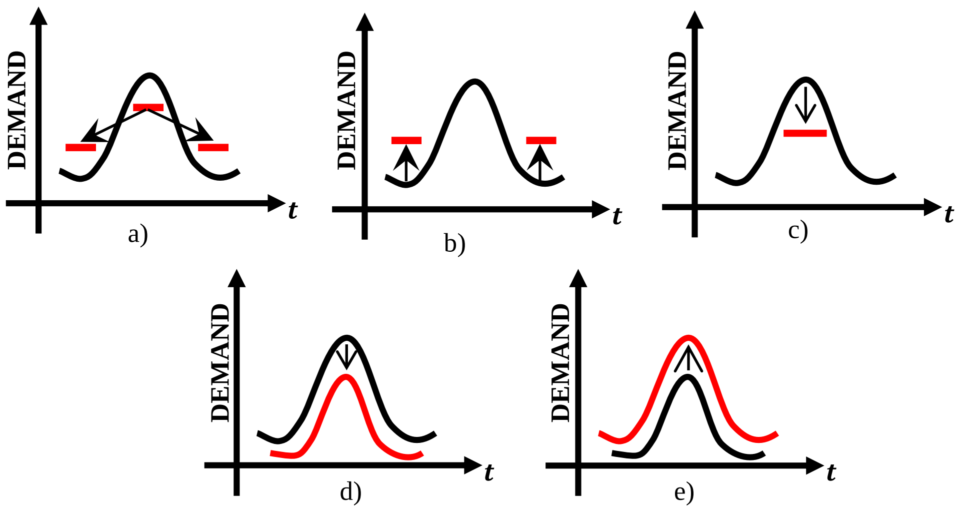


Figure 2. DSM Strategies, a) Load Shifting, b) Valley Filling, c) Peak Clipping, d) Strategic Conservation, e) Demand Growth [16].

Equilibrium price varies according to supply and demand conditions. A decrease in the energy price affects the system in a way that decreases the supply and increases the demand, while an increase in the energy price, on the contrary, affects the system in a way that increases the supply and decreases the demand. The vertical axis represents the amount of energy (N), and the horizontal axis represents the energy price (p). The point where the production (S) and demand (D) curves are equal to each other shows the optimal energy price (p_{ort}), in other words, the equilibrium point (Q). This is characteristically shown in figure 3 [10].

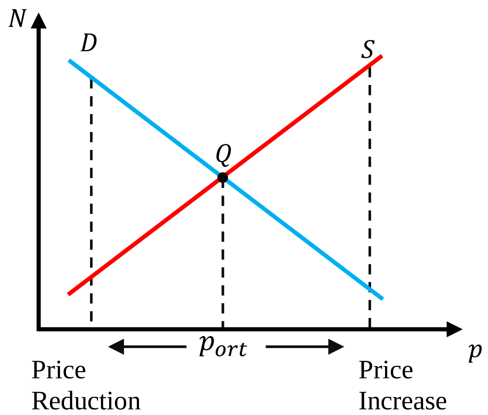


Figure 3. Equilibrium Price Point and Production-Demand Graph [10].

If the error signal is defined with e to express the instability between demand and supply, the point where these points are equal to each other can be used to express the equilibrium point Q . The error signal e is mathematically as follows [10].

$$e = D - S \tag{1}$$

If the error signal e is greater than zero ($e > 0$), it means that the production is less than the demand ($D > S$). This situation causes energy scarcity due to the fact that the supply is less than the demand. This situation reduces energy efficiency as it will cause overproduction. "Virtual Demand (D_S) " is used in the simulations to create a resistance against the $e > 0$ situation and to prevent energy shortages by providing overproduction. In this case, the error signal should be rearranged as follows [10].

$$e = D + D_S - S \tag{2}$$

The closed-loop PID block diagram designed for energy pricing used in the simulation is given in Figure 4. In the block given as the production model, there are thermal, hydroelectric, solar and wind supplies, respectively.

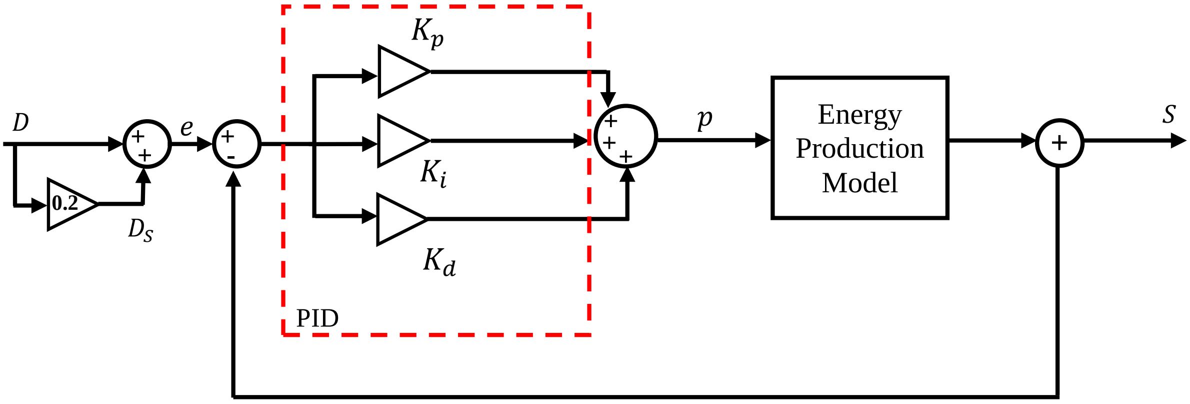


Figure 4. Closed-loop PID block diagram simulation model for dynamic energy pricing [10].

3. Dynamic Energy Pricing Using Pole Placement Method with PID Controller

In the pricing study using a PID controller, it is necessary to give the energy productions of the consumer community as an analytical model to ensure that the simulations continue efficiently. For this purpose, the following energy production model was used in the simulations [10].

$$S_d(p) = \sum_{i=0}^{d} a_i \cdot p^i \tag{3}$$

Here d is the degree of the polynomial and a_i is the coefficient of the polynomial. The main point accepted here is that the total installed energy capacity of the producers (C_{max}) is assumed to be greater than the demand. Another important consideration for the completion of this production model is the modeling of the delay in production. The capacitive delay model given here is based on the charge and discharge kinetics of the capacitor circuit element. τ parameter is a time constant. Then, considering this delay, the energy production model can be rearranged as follows depending on the s time domain [10].

$$S = S_d(p) \cdot \frac{1}{\tau s + 1} \tag{4}$$

In addition, the generation models, time constants and installed powers of thermal, hydroelectric, wind and solar energies with a total installed power of 50000 MW used in the simulations are given in Table 1 below.

Table 1. Simulation scenario with 50000 MW installed power

Source Type	C_{max} (MW)	Time Constant (h)	Production Model
Thermal	10000	0.31	$0.01p^2 + \frac{2.5p}{0.31s+1}$
Hydropower	30000	0.052	$0.01p^2 + \frac{2.5p}{0.052s+1}$
Wind	6000	0.084	$0.01p^2 + \frac{2.5p}{0.084s+1}$
Solar	4000	0.052	$0.01p^2 + \frac{2.5p}{0.052s+1}$

To determine the K_P, K_i and $K_d$parameters in the PID controller, it is first necessary to convert the system to a 2nd Order system. The transfer function of the system used in this study is given below.

$$G(s) = \frac{K}{\tau \cdot s + 1} \tag{5}$$

K is a constant and 1 is taken. The general transfer function of the PID controller is as follows.

$$C(s) = K_p + \frac{1}{s} \cdot K_i + s \cdot K_d = \frac{K_d \cdot s^2 + K_p \cdot s + K_i}{s} \tag{6}$$

The closed-loop transfer function of a system is as follows.

$$T(s) = \frac{G(s) \cdot C(s)}{1 + G(s) \cdot C(s)} \tag{7}$$

If the expressions in the equation are written in their place, the closed-loop transfer function of the system is converted to the 2nd order and can be rewritten as follows.

$$T(s) = \frac{K_d \cdot s^2 + K_p \cdot s + K_i}{(K_d + \tau) \cdot s^2 + \left(K_p + 1\right) \cdot s + K_i} \tag{8}$$

The expression of a quadratic system in control theory is given as follows.

$$T(s) = \frac{{\omega_n}^2}{s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + {\omega_n}^2} \tag{9}$$

Here ω_n is the natural frequency of the system and ζ is the damping ratio. The characteristic equation of this expression is as given.

$$\Delta(s) = s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + {\omega_n}^2 = 0 \tag{10}$$

Since the characteristic equations for both functions will be equal to 0, they will be equalized to each other and the PID parameters will be found by changing the natural frequency. Then the two equations can be written as:

$$s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + {\omega_n}^2 = (K_d + \tau) \cdot s^2 + \left(K_p + 1\right) \cdot s + K_i \tag{11}$$

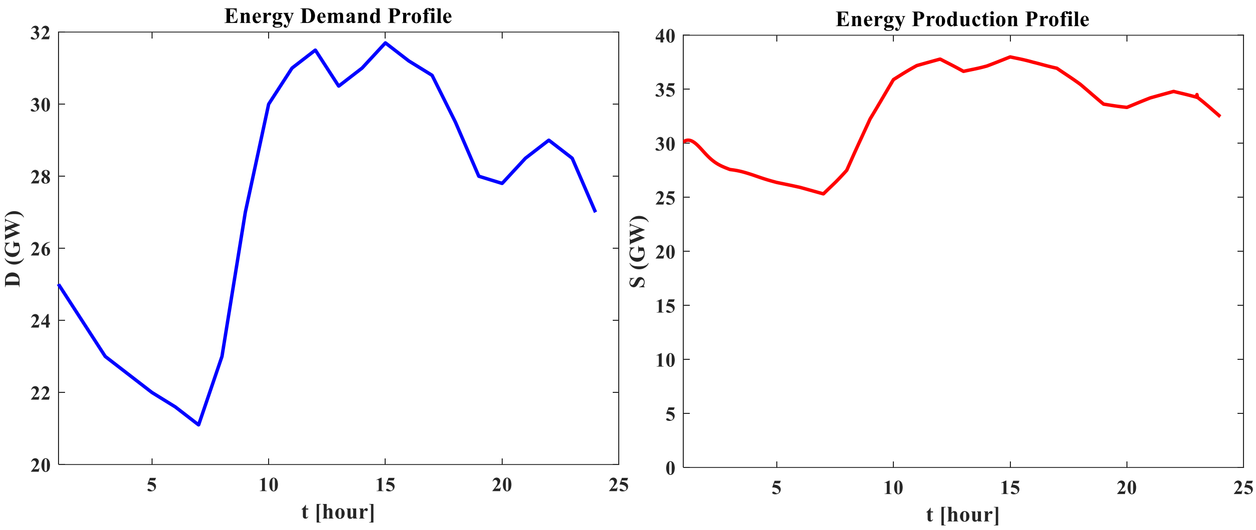
The time constants for 4 separate sources are different. The time constant τ 0.31 h was taken for this study. The damping ratio is taken as $\zeta = 0.6$ and the natural frequency ω_n is taken as 1 rad/s and 4 rad/s, respectively. Thus, the PID coefficients found by the pole placement method are given in Table 2 below.

Table 2. PID parameters calculated by pole placement method

		K_p	K_i	K_d
ζ= 0.6	$\omega_n = 1\ rad/s$	0.2	1	0.69
	$\omega_n = 4\ rad/s$	3.8	16	0.69

3.1. Simulation Results

The 24-hour demand curve and the total production curve for this system are given in Figure 5. Here, it is seen that the production is higher than the demand and the PID controller adjusts the error signal to bring the energy production closer to the demand [10].



a) b)

Figure 5. Simulation results: a) Demand profile, b) Energy production profile [10].

Figure 6 below together shows the demand profile and the production response in the multi-resource simulation study. One reason for the surplus in production is the virtual demand added to the simulation study to prevent the energy shortage situation [10].

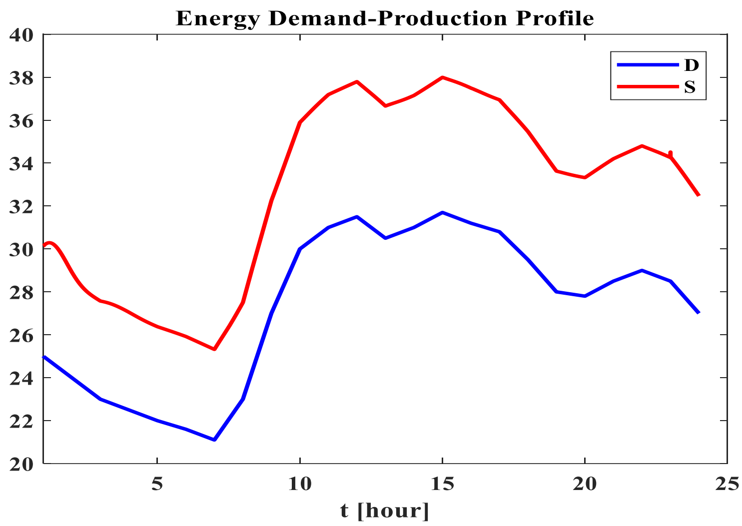


Figure 6. Demand and production profile [10].

The production of thermal, hydroelectric, wind and solar energy during the day, respectively, is shown in Figure 7 [10].

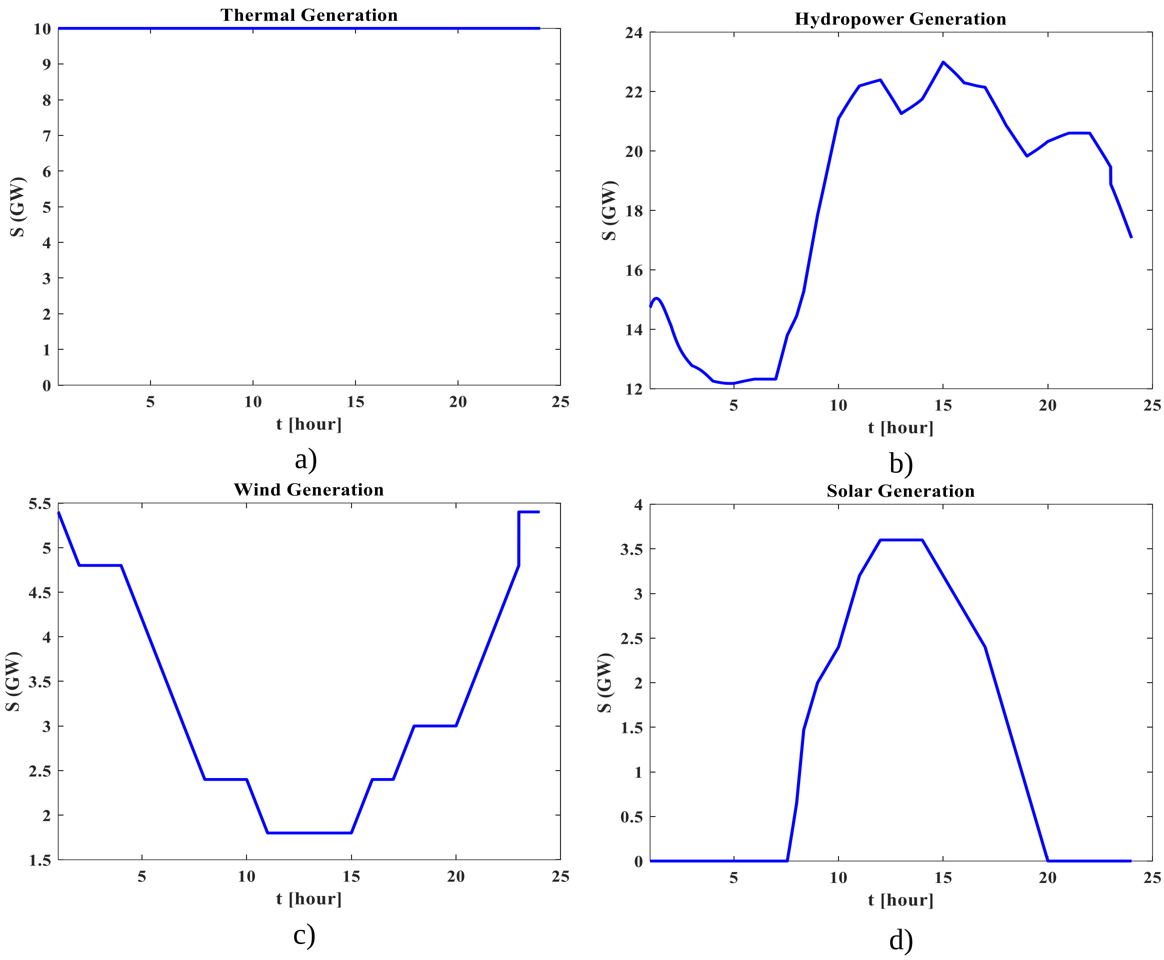


Figure 7. Multi-source production profiles; a) Thermal energy generation, b) Hydropower energy generation, c) Wind energy generation, d) Solar energy generation [10].

Figure 8 and figure 9 are pricing curves provided by the PID system during one day. It is seen that the PID controller provides a stable energy price signal against the demand data that changes during the day. The fluctuation seen in the price change is related to the settlements of the poles. Because the change of natural frequency changes the pole positions. By increasing the natural frequency, suitable PID values can be determined according to the positions of the poles in the left half plane. But in these values, the price balance has been achieved. After the sudden increase in demand between 08:00 and 10:00, there were increases and decreases in demand. However, the price equilibrium was achieved and was not affected by the changes in demand.

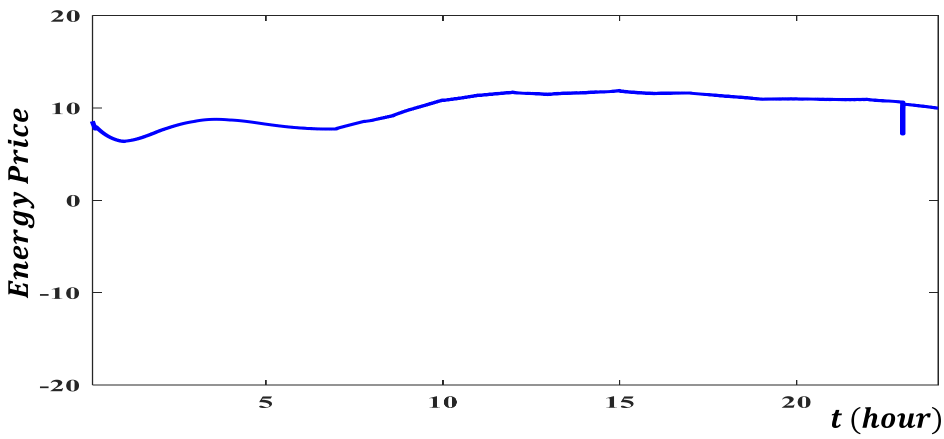


Figure 8. Dynamic energy pricing of the PID controller ($\omega_n = 1\, rad/s$)

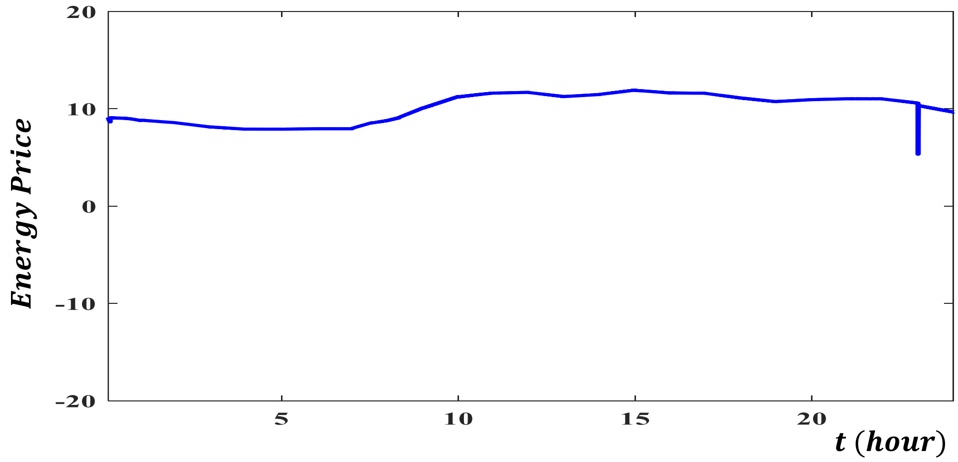


Figure 9. Dynamic energy pricing of the PID controller ($\omega_n = 4\, rad/s$)

In addition, the instantaneous change in energy demand is given in the simulation study to examine the effect of the change in energy demand on the price. A sudden drop at 12:00 and a sudden rise at 22:00 is given. Figure 10 shows the changing energy demand and the production provided by PID control. In Figure 11 (a) and (b), the price signal responses given by the PID controller, these sudden peaks and drop of changing demand are given. PID control provides high profits for producers by increasing the price signal against the sudden increase in energy demand. Likewise, the price signal for the sudden decrease in demand also decreased, and it was observed that producers reduced their production due to costs.

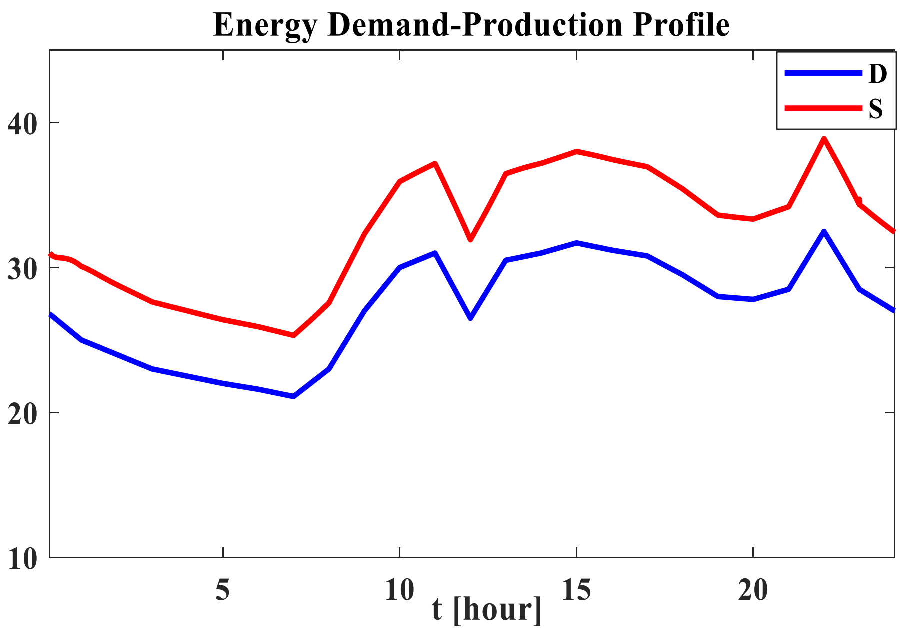


Figure 10. Sudden Decrease (Dip) and Increase (peak) in consumer demands

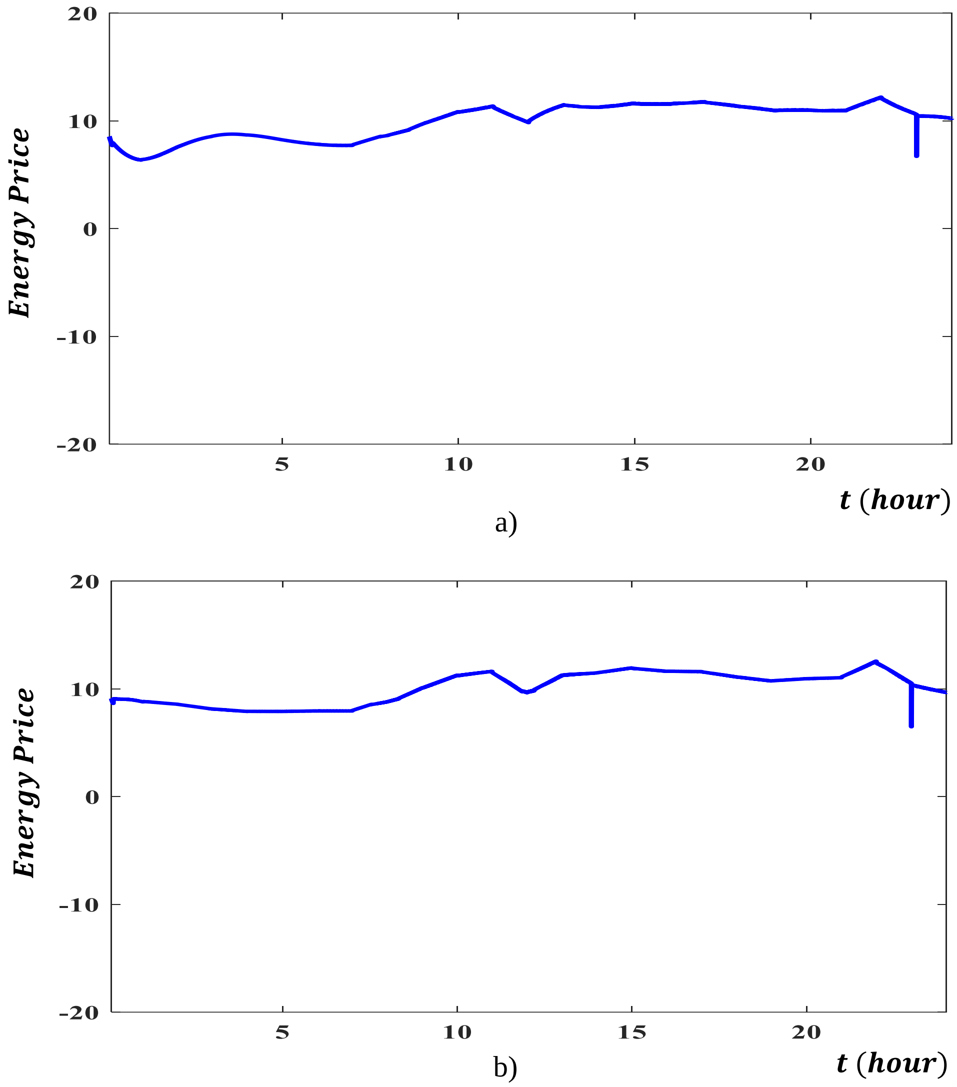


Figure 11. Price signal of PID controller: a) $\omega_n = 1\ rad/s$ b) $\omega_n = 4\ rad/s$

4. CONCLUSIONS

In this study, with the inclusion of distributed generation in the smart grid, the price balance is achieved with the PID controller by using the pole placement method. Simulations were carried out in MATLAB/SIMULINK package program for a multi-source system with 50 GW installed power. First of all, the system has been transformed into a 2nd degree system. Then, the PID coefficients were calculated with the variation of the natural frequency. It has been shown that in response to the changing demand, the production maintains the price balance and maintains the energy efficiency by controlling the error signal with the PID controller. The PID controller is proven to respond instantly and online to sharp demand changes. The reason for the change in the PID coefficients with the change of the natural frequency depends on the position of the poles on the axis, and this subject can be continued in another study. It has been seen that dynamic energy pricing is controllable and manageable in the energy network and it provides energy price balance by adjusting the PID parameters against the changes in demand.

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