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PSCAD/EMTDC SİMÜLASYON PROGRAMI KULLANILARAK BİR MİKRO ŞEBEKENİN YÜK FREKANS KONTROLÜ (LFC)

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ÖZET

Güç kalitesinin sürekliliği, günümüzün modern şebeke yapısında ve geleceğin akıllı şebeke yapısında önemlidir. Yenilenebilir enerji kaynaklarının mevcut şebeke sistemine dâhil edilmesi ve teknolojik cihazların kullanımının artması güç kalitesinin düşmesine neden olacaktır. Güç sistemi harmonikleri, güç kalitesinde düşüşe neden olan faktörlerden biri olarak nitelendirilebilir. Bu faktörün etkileri önlenmezse, güç sistemlerinin performansında ve güvenilirliğinde ekonomik kayıplara neden olacak bir düşüşe yol açacaktır. Bu çalışmada, yakın gelecekte hayatımızda çok önemli bir rol oynayacak ve muhtemelen yeni şebeke altyapısına örnek olabilecek bir mikro şebeke tasarlanmıştır. Bu mikro şebeke, PSCAD/EMTCD programı ile simule edilmiştir. Güç sistemi simülasyon programları arasında PSCAD/EMTDC programı, gelişmiş grafik olanakları ve gerçek zamanlı model uygulamaları gibi öne çıkan özelliklerinden dolayı tercih edilmiştir. Mikro şebekelerin, sistem güvenilirliğini artırmak, dağıtık üretim (DG) birimleri arasında paylaşmak ve frekans-gerilim değerlerini belirli sınırlarda tutmak için kontrol yöntemlerinin kullanması gerekmektedir. Bu çalışmada en çok kullanılan yöntemlerden biri olması ve literatürdeki başarısı kanıtlanmış olması nedeniyle droop control yöntemi tercih edilmiştir. Tasarlanan sistem dört farklı senaryo ile test edilmiş ve sonuçlar tartışılmıştır. Güç kalitesini etkileyen nedenlerden biri olan yük frekansı kontrolü (LFC) özellikle analiz edilmiştir. Tüm senaryolardan elde edilen sonuçlara göre, dört numaralı senaryo hariç, frekans aralığının 58-60 Hz bandını geçmediği belirlenmiştir. Elektrikli araçların (EV) sisteme dâhil edilmesi durumunda yeni çözüm önerileri sonucunda sağlanan ek maliyetler ve avantajlar değerlendirilmiştir. Özellikle çift yönlü enerji akış (V2G) özelliğine sahip elektrikli araçların şebekeye bağlanmaları sonucu ortaya çıkan yeni durumlar incelenmiştir.

Anahtar Kelimeler: *LFC, Mikro Şebeke, PSCAD/EMTDC, Güç kalitesi, Akıllı şebeke*

LOAD FREQUENCY CONTROL (LFC) OF A MICROGRID USING PSCAD/EMTDC SIMULATION PROGRAM

ABSTRACT

Continuity of the power quality is important in the modern day grid structure and the smart grid structure of the future. Incorporating the renewable energy sources to the present grid system and the increase of the usage of technology devices will cause the power quality to decrease. Power system harmonics can be characterized as one of the factors that causes a decrease in the power quality. The effects of this factor, if not prevented, will lead to a decrease in the performance and reliability of power systems which will cause economic losses. In this study, a micro grid, which will play a very important role in our lives in the near future and can possibly be an example to the new grid infrastructure, has been designed. This micro grid has been simulated with the PSCAD/EMTCD program. Among the power system simulation programs, the PSCAD/EMTDC program was preferred because of its outstanding features such as advanced graphics facilities and real-time model applications. Micro grids need to use control methods to increase system reliability, to share power between distributed generation (DG) units and to keep frequency-voltage values at certain limits. Droop control method is preferred in this paper since it is one of the most widely used methods and its success in literature has been proven. The designed system has been tested with four different scenarios and the results have been discussed. According to the results obtained from all

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scenarios, except for scenario number four, it was determined that the frequency range did not exceed the 58-60 Hz band. Load frequency control (LFC), one of the reasons that effect the power quality, was particularly analysed. The additional costs and the advantages provided as a result of novel solution proposals in the case of electric vehicles (EV) being incorporated to the system were evaluated. Particularly, provision of bidirectional energy flow of the vehicle to grid (V2G) featured electrical vehicles to the grid was examined.

Keywords: *LFC, Micro grid, PSCAD/EMTDC, Power quality, Smart grid*

1. Introduction

Electrical energy; is a clean type of energy which is easy to use, transmit and control, as well as, its easy transformability into other types of energy and bringing meaning into our lives. This energy not only increases the quality of human life, but is also one of the essential requirements of industrial production, as well as being the most important factor in providing social and economic progress. Increasing energy prices, global warming and climate changes, population growth both in the whole world and in the developing countries as well as the elevation of living standards, an increase in the energy demand in parallel with the developments in industry and technology, continuation of the dependency on the fossil fuels in the near future which are rapidly running out, providing security of supply and the developments in the field of novel energy technologies make the countries seek for new alternatives. This shows that there is a high incidence of need to use renewable energy sources for the production of electrical energy. Although there is a large variety of renewable energy sources (such as biomass, geothermal, solar energy, wave, landfill gas), this study has been limited to hybrid renewable energy systems consisted of PV panel and micro hydroelectric generating units [1-2].

The Earth is quite rich in terms of variety and potential of renewable energy sources. The cost of these energy sources are quite low. Due to their renewability, they never run out and, unlike conventional fuels, they do not become a threat to neither the environment nor human health. However, the discontinuity and, naturally, the unpredictability of renewable energy sources prevent them from being commonly used. This problem can be solved with the proper management strategy and storage system, which resolves the time inconsistency between energy generation and load requirement. Electrical energy, which is traditionally generated from sources found away from residential areas, is being increased to high voltages in order to decrease the losses, as well as being transmitted as alternating voltage and distributed by lowering it to low voltage at the distributing point. At first, electrical energy was generated centrally and was transmitted and distributed to long distance areas. Whereas, in recent years, instead of electrical energy generation being central, the focus in decentralised generation systems and micro grids have increased due to environmental issues which are caused by the increasing consumption and traditional energy generation.

Some problems have arised in result of high incidence of renewable energy sources being included into the present system. The old system's conversion to the new generation system will bring many changes along with it. Innovations such as different grid configurations, operational and optimum strategies have challenged old and unidirectional system designs. Besides manufacturing, control, and communication systems being parts of the components of the grid system, new expenses such as electrical vehicles (EV) are close to being included to grid system on the consumption side.

Automatic Generation Control (AGC) is one of the most studied subjects that researchers have presented solution suggestions for, in recent years. Load Frequency Control (LFC) is used as a part of AGC in order to keep the constant frequency and regulate the interconnection power flows. Frequency control is important in terms of maintaining the power quality. Energy storing batteries in micro grids, superconductors, supercapasitors, flywheels and electrical vehicles are important for maintaining the power quality of the system. Electrical vehicles that are capable of specifically having vehicle to grid (V2G) bidirectional energy flow, have a vital importance for the grid system. Electrical vehicles having portable batteries bring an advantage for the system.

An Electric Vehicle is an alternative transportation option that has no exhaust gas emission and produces minimum amount of sound. In comparison to the conventional internal combustion engine vehicles, EV uses electric motor and battery energy for drive with higher productivity and a lower operating cost. With the increase of the electric vehicles, the demand for electrical energy will increase and the burden of grid system will increase immensely. If this burden is not kept under control, it may cause frequency departure and even instability of the power system. More power needs to be reserved for the frequency control of the grid. For this purpose, the usage of energy storage technologies may be required.

Elsisi et al. have suggested a Bat Inspared Algorithm (BIA) based hybrid approach for blocking frequency oscillations in the power system [3]. Aziz et al. have carried out a study on surge frequencies which might arise from a wind station being included later to a hybrid power system that consists of different manufacture stations [4]. Dong et al. have presented a new aproach of solution based on active disturbance rejection control (ADRC) method to minimize external disturbance, frequency oscillations, systemic imbalances and control errors [5]. Tan et al. have studied Linear active disturbance rejection control (LADRC) method for load frequency control (LFC) [6]. Sekhar et al. have suggested a hybrid PID controller based on Firefly Algortihm (FA) for frequency control [7]. Maslo et al. have investigated the strategies of active power and frequency control in the state of island operation mode for a smart grid [8]. Khooban et al. have pointed out that large frequency alterations may form in case of production and demand imbalances in the smart grids and to overcome this problem, the electrical vehicle batteries can be used to feed the system. Additionally they have used a PI controller optimized with Modified Harmony Search Algortihm (MHSA) to resolve the disadvantages of the micro grid [9].

Waraich et al. have presented an iterative model based on more than one interconnecting energy bearing systems in order to efface the negativities that may occur if electrical vehicles are included in the grid [10]. Tan et al. made a broad review study regarding the benefits and difficulties of the electrical vehicles on grid system [11]. Falahati et al. have suggested a new smart charging method based on ambigious logic method to prevent frequency flactuations if the electrical vehicles are included into the grid as loads [12]. The performance of the suggested method were compared to a PI controller optimized for controlling frequency. Panwar et al. have studied on a multi-purpose optimization method to maximize the level of the line losses, operating cost as well as stored energy value; rather than a simple approach to minimize the line losses in the grid for optimizing micro grid parameters [13]. Fard et al. on the other hand, have suggesed a new stocastic method regarding the optimum management of electrical vehicle charging in the micro grid [14]. Kamankesh et al. have used Monte Karlo simulation which is a known method for the management of micro grid [15]. Aliasghari et al have suggested an energy management model with the purpose of decreasing the energy cost [16]. Drude et al. have presented a new approach study for the energy market of Brasil [17]. Peng et al have carried out a study that reviewed the delivery strategies of electrical vehicles included in the grid for frequency regulation [18]. Shaukat et al. have also carried out a comphrehensive review study on the effects of micro grid and electrical vehicles on the system [19]. Bahramara et al. have suggested a novel management model in order to formulize micro grid's operating issue in the best way possible [20]. Ferro et al. have suggeted an optimization method in planning the electrical vehicles and system in the smart grid in the most proper way [21].

It is difficult to connect renewable energy sources directly to a main grid. A microgrid serves as an interface between distributed generation system and the utility grid. This interface is a low voltage distribution system consisting of DG units, batteries and load. A microgrid can be operated separately or it can also be connected to the main distribution system. The voltage form generated from DG units is DC. The majority of loads connected to the main grid system require AC voltage. Therefore, the inverters are very important for converting DC voltage to AC voltage. In addition, important task of the inverter can be said that interface between DG unit, load and system grid [22]. In order to increase system reliability, the inverters are connected in parallel to the micro grid system. Because if the inverter fails, the other modules of the system must be able to give the load the power it needs [23]. Many control methods have been proposed for high performance operation of the inverters connected in parallel with the system. Voltage and frequency droop control is a widely used method among these methods and is also accepted as a reliable method [24-26]. For these reasons, it is considered appropriate to use the droop control technique for the microgrid model designed.

2. Synchronous Generator Equivalent Circuit Model

Permanent magnet synchronous generator (PMSG) was used in this study. Assuming the fact that the surface of PMSG is magnetic, mathematical model on synchronous reference frame was stated with (1)-(5) equations.

$$V_q = Ri_q + L\frac{di_q}{dt} + \omega_e \lambda_m \tag{1}$$

$$V_d = Ri_d + L\frac{di_d}{dt} + \omega_e L_d i_q \tag{2}$$

$$T_g = J\frac{d\omega_r}{dt} + B\omega_r + T_m \tag{3}$$

$$T_m = \frac{3P_p \lambda_m}{2} i_q \tag{4}$$

$$\theta_e = P_p \theta_r \tag{5}$$

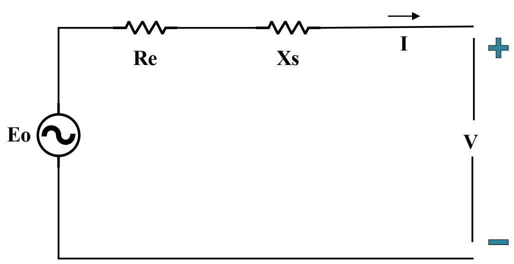


Figure 1. Synchronous Generator Equivalent Circuit Model

Here, θr stands for rotor position/location, ωr rotor angle velocity, Vd, Vq, id, iq d and q axis voltages and currents, Tg, Tm, θe generator momentum, mechanical moment and electrical angle, λm, Pp, J, B magnetic flux, number of poles, inertial momentum and friction constant respectively.

3. Solar Cell Equivalent Circuit Model

In this study, a general solar cell equivalent circuit model and related equations were given. In figure 2, the circuit diagram relevant to a general model is seen. The related equations to this circuit were given between (6)-(9).

Abbreviations in electrical equivalent circuit;

Ipv: Electric current generated by sunlight

Id: Diode current

I: Load current

Rs: Series resistance

Rp: Parallel resistance

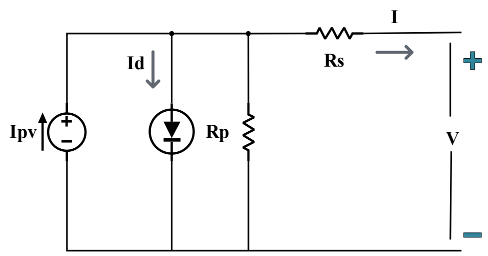


Figure 2. Solar Cell Equivalent Circuit Model

Here, λ, shows radiation as kW/m2, Isc short circuit current of solar cell at 25 C, Ki short circuit current of solar cell constant for temperature, T working temperature of solar cell as K. At Equation (6) Reverse Saturation curret was given as Irs. Also, Voc stands for open circuit voltage of solar cell, Ns number of moduls in the solar cell, k boltzman constant, A ideal factor depending on the material used.

$$I_{rs} = I_{scr} / \left[e^{\left(qVoc/NskAT\right)} - 1 \right] \tag{6}$$

Is also stands for saturation current which varies depending on the value given for solar cell. Saturation current was given at equation (7). In which *Tref* shows the reference temperature of the solar cell, *Eg* the band range energy of the semi-conductor used in the solar cell, q electronic charge.

$$I_s = I_{rs} \left(\frac{T}{T_{ref}} \right)^3 e^{\frac{\left(q^*Eg\right)}{\left(Ak(1/T_{ref} - 1/T\right)}} \tag{7}$$

The current I is expressed as in equation (8).

$$I = I_{pv} - I_s \left[e^{\frac{\left(q^*\left(V + IR_s\right)\right)}{\left(AkT\right)}} - 1 \right] - \frac{\left(V + IR_s\right)}{R_s} \tag{8}$$

In Figure 2, if the diode current is *Id,* it is expressed as given at Equation (9). There while V_d is diode voltage and V_T is temperature voltage.

$$I_d = I_o e^{\left(V_d / V_T - 1\right)} \tag{9}$$

4. Battery Equivalent Circuit Model

The battery model used here is the modified form of a basic battery model. A fixed resistor, which is used for a basic battery model, turns into a resistor that changes circumstantially. Here, internal resistance R_{in} varies depending on the battery's fullness.

$$R_{in} = \frac{R_o}{S^k} \tag{10}$$

(Voc) given in Figure 3 shows the open circuit voltage, R_o given in equation (10) shows internal resistance of a full battery, k shows capacity coefficient, and S shows the state of the varying fullness of battery between 0 and 1.

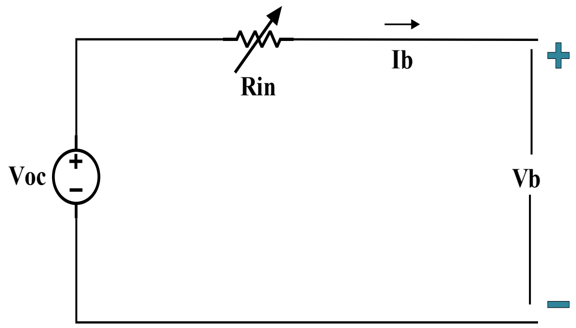


Figure 3. Battery Equivalent Circuit Model

5. Droop Control Method

In islanded microgrids, distributed generation units are planned to meet the power demand from the load. Being able to meet the demands power is only possible if the voltage and frequency values can be kept within certain limits by distributed generation units. In addition, the ability to share power between distributed generation units is important for reducing system losses. Many control strategies have been adopted in the literature to solve these problems. In this study, droop control method which is one of the most preferred methods in the literature is used as control method. Active and reactive power can be defined by the following two equations.

$$P = \frac{EV}{X}\sin\phi \tag{11}$$

$$Q = \frac{EV\cos\phi - V^2}{X} \tag{12}$$

where X represent output reactance of inverter, Ø phase angle between the output voltage of the inverter and the voltage of the bus, E the magnitude of the inverter output voltage, V amplitude of grid output voltage. As can be seen from equations (11-12), the active power depends on the phase angle variable and the reactive power depends on the voltage variable. The droop control method with the general expression is indicated by the following equations (13-14).

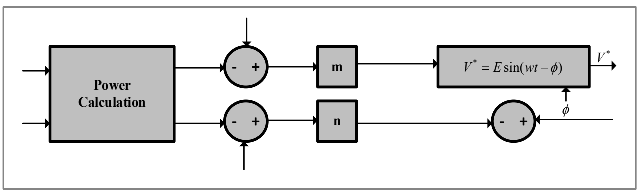
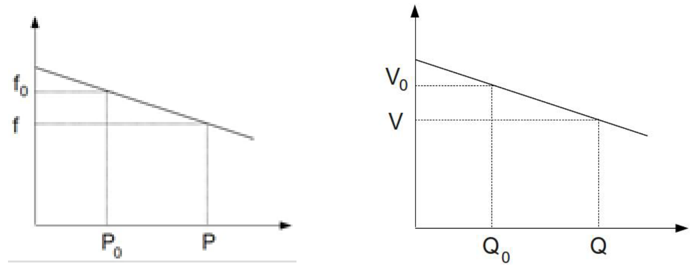


Figure 4. Block diagram of droop controller

$$\omega = \omega^* - m(P - P_i) \tag{13}$$

$$E = E^* - n(Q - Q_i) \tag{14}$$

where ω^* represent angular frequency of output voltage, E^* voltage amplitude when the system is not loaded, m and n droop coefficients, P and Q active power and reactive power values, Pi and Qi instantaneous active and reactive power values. Figure 4 has an overview of the droop control strategy.



(a) (b)

Figure 5. (a) Frequency droop characteristic (b) Voltage droop characteristic

The frequency drop in Figure 5 can be explained; as seen from the figure, the frequency drops from f_0 to f, in which case the power output value of the inverter increases from P_0 to P. The system will require extra active power generation as the system will be overloaded with the reduced frequency. In the case of increased active power generation, the reduction of the frequency will be prevented, and the droop control method will develop a strategy to keep the system frequency constant. At the same time, the droop characteristic will help multiple modules to share the load appropriately to control the load [27].

6. Microgrid Model

In this study two conventional permanent magnetic synchronous generator at the power of 300 kW and 500 kW were designed for manufacturing in a PV power plant in which their power vary depending upon the sun radiation. Scenarios formed in this grid model have been modelled on the PSCAD/EMTDC simulation program.

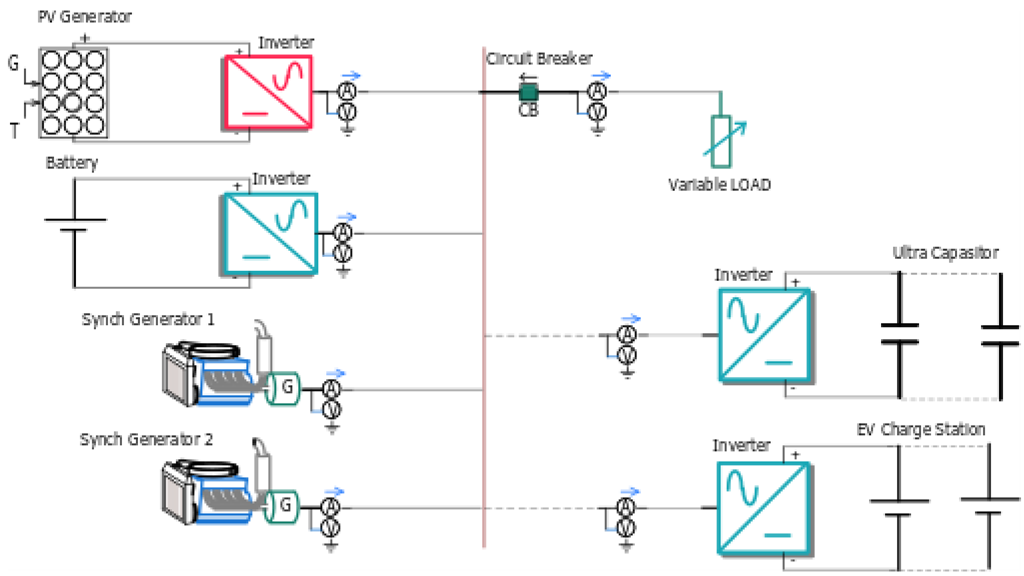


Figure 6. Microgrid Model

Four different case scenarios were formed for the model and the current, voltage, frequency variables of the system were analyzed. For this study, we tried to keep the frequency value within the range of 58-60 Hz in all scenarios by using control variables. The scenarios for the model were listed on the Table 1.

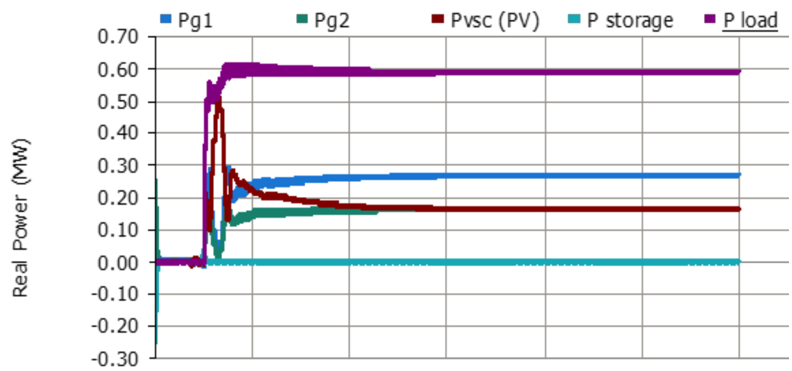
Table 1: Scenarios Created for Microgrid

Scenarios	Gen.1	Gen.2	Gen.PV	Battery	Active Load (kW)	Reactive Load (kVar)
SCNR1	Actv	Actv	Actv	Actv	600	200
SCNR2	Actv	NaN	Actv	Actv	600	200
SCNR3	NaN	Actv	Actv	Actv	600	200
SCNR4	NaN	NaN	Actv	Actv	200	50

6.1. Scenario-1

When the simulation program activated for the scenario 1, the active power distribution for the stable state were as follows: Pg1: 269 kW, Pg2: 162 kW, Ppv: 174 kW, Pstorage: -18 kW, Pload: 587 kW.

The system's temporary case uncertainty does not take long as seen on Figure 7 (a). As understood from the active power distribution, the battery charges by transferring power from the system. Since all generators are turned on, load (burden) value can be met easily without being exposed to any difficulty. The systemic frequency can easily reach the targeted value of 60 Hz. As can be seen from the graphs of the current and voltage of the system, harmonic distortion effect in the 3-phase sinusoidal diagrams can be stated as not significant. As understood from this situation that the system can be stated as being in an ideal working range.



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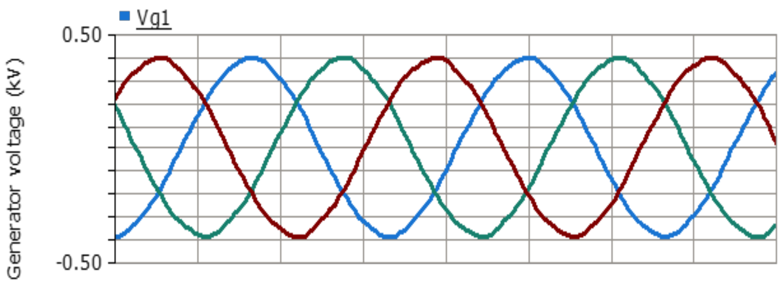

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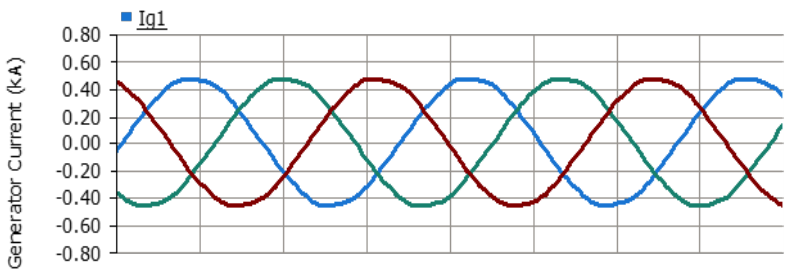

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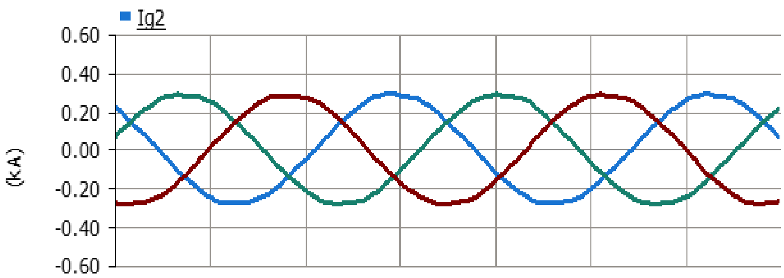

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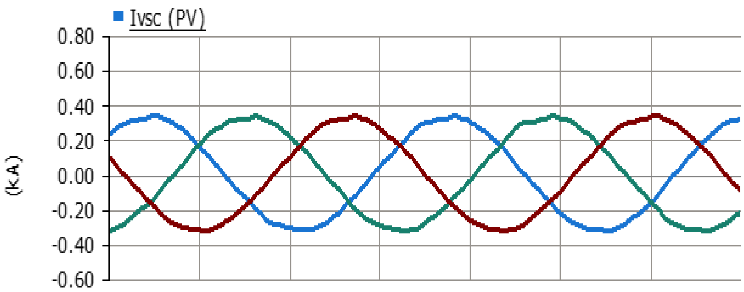

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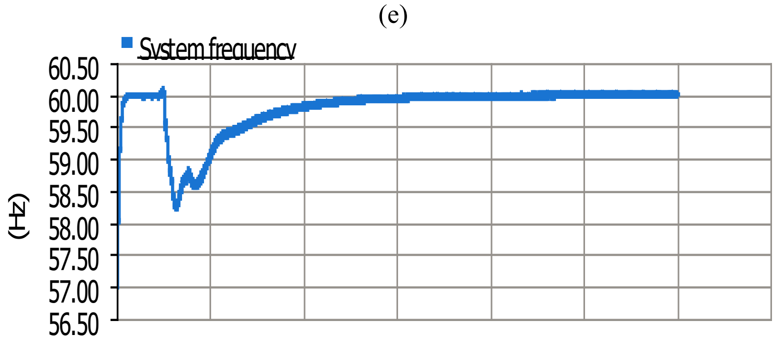
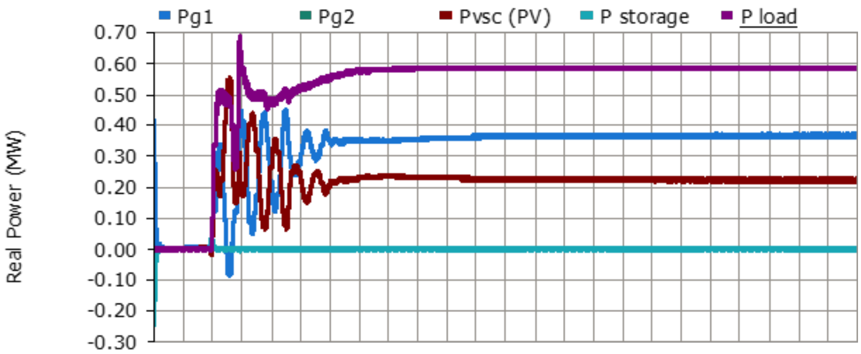


(f)

Figure 7. System variables for Scenario 1 in the Micro Grid Model a) Power distribution graph of the system b) 3-phase voltage graph of no. 1 synchronous generator c) 3-phase voltage graph of no. 1 synchronous generator d) 3-phase voltage graph of no. 2 synchronous generator e) Inverter output 3- phase PV current graph f) System Frequency

6.2. Scenario-2

For the second scenario, the simulation program was activated and the system's stable state active power distributions were determined as follows. Pg1: 364 kW, Pg2: 0 kW, Ppv: 221 kW, Pstorage: -2 kW, Pload: 583 kW. The system's temporary state instability lasts longer than the first scenario as seen on Figure 8 (a). The reason for this can be attributed to the fact that the demanded load/burden amount is close to reaching the power generation limits of the system. Because the system was concentrated on supplying the load value, power transfer to the battery system decreased. The system had a difficulty to compensate the demanded burden amount because generator 2 was not turned on. The system frequency has reached the targeted value as a result of temporary scenario oscillations. After the system passing to a stable state, there has been apparent improvement on the current and voltage graphics. For the system to get over temporary instability state scenario it is needed to take precautions like using superconductors, supercapacitors, and backup battery groups.



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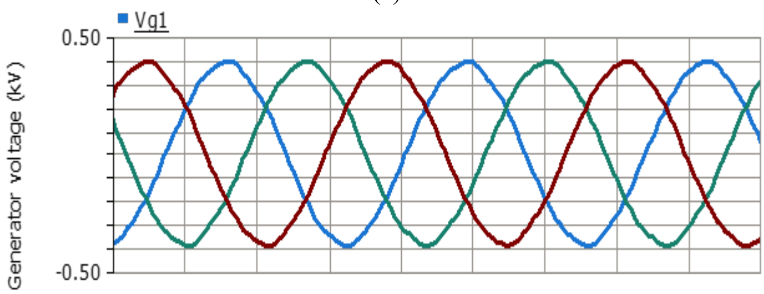

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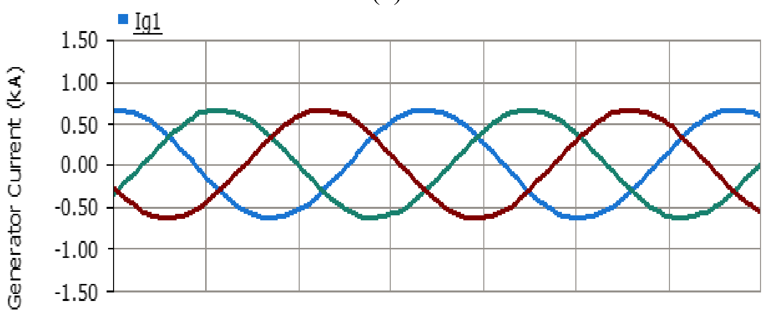

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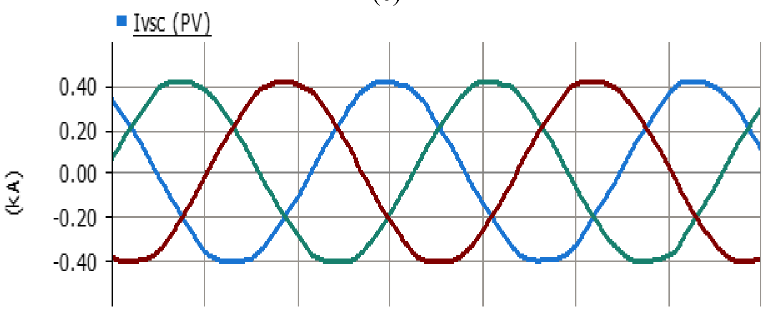

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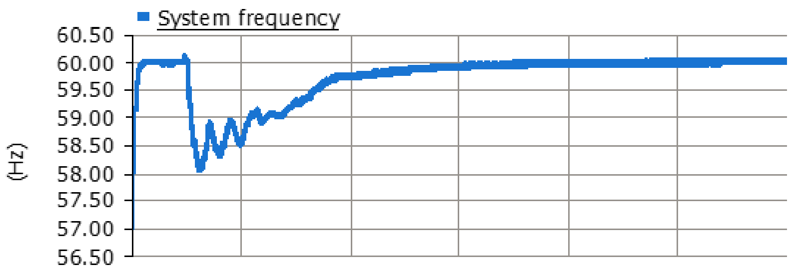
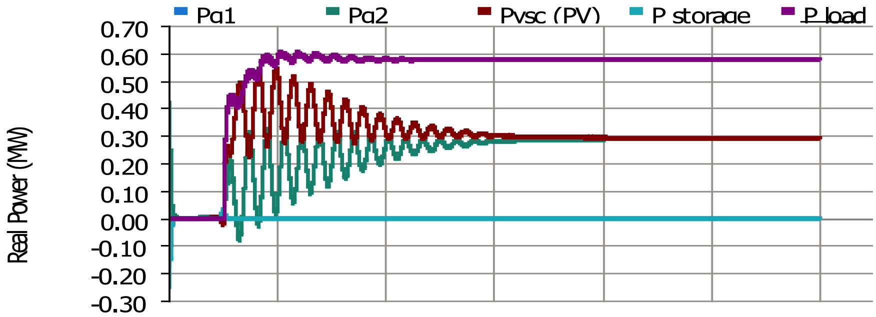


(e)

Figure 8. System variables for Scenario 2 in the Micro Grid Model a) Power distribution graph of the system b) 3-phase voltage graph of no. 1 synchronous generator c) 3-phase voltage graph of no. 1 synchronous generator d) Inverter output 3- phase PV current graph e) System Frequency

6.3. Scenario-3

For the third scenario, when the simulation program is activated, the system's active power distribution for stable state was measured as follows: Pg1: 0 kW, Pg2: 290 kW, Ppv: 290 kW, Pstorage: -3 kW, Pload: 587 kW. As seen on Figure 9 (a), it has taken a long time for the system to get to a stable state. The system has faced some difficulties to meet the demanded loads. In ideal systems, when the temporary unstable states take a long time, it reduces power quality of the system considerably. Power quality, voltage and frequency fluctuations as well as the resulting harmonics are the biggest problems that grid systems come across.



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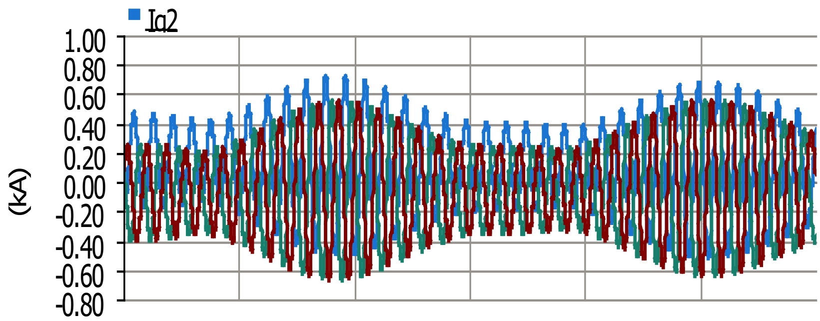

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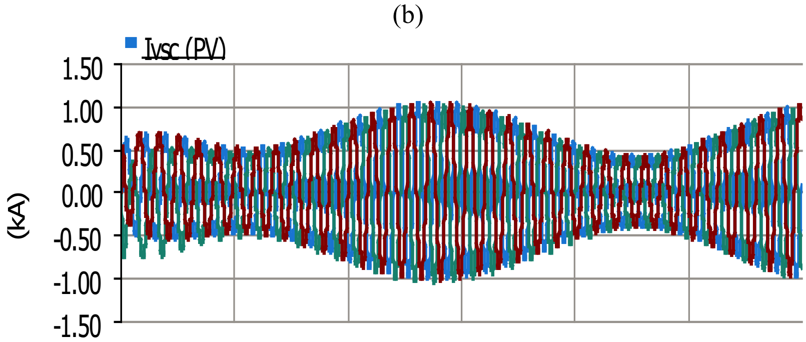
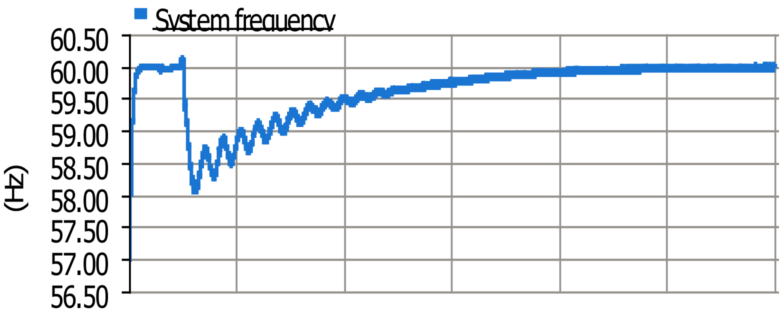


(c)



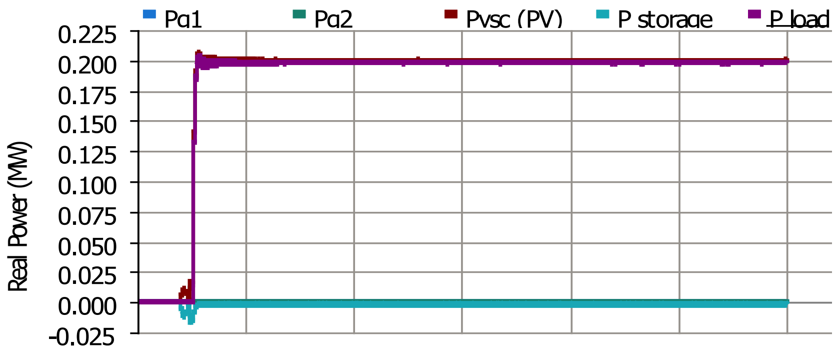
(d)

Figure 9: System variables for Scenario 3 in the Micro Grid Model a) Power distribution graph of the system b) 3-phase voltage graph of no.2 synchronous generator c) Inverter output 3-phase PV current graph d) System Frequency

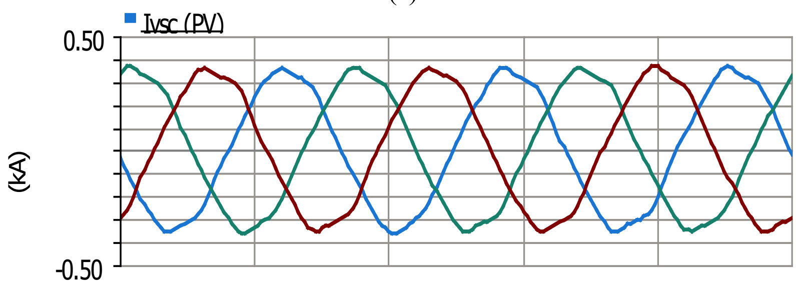
The power transfer to the battery system has decreased to the almost zero point. The system frequency has reached the objective as a result of temporary scenario oscillations. The system's 3-phase current values have experienced unfavorable oscillations that affect the power quality negatively. For this scenario, besides certain precautions such as using superconductors, supercapacitors, and spare battery groups, it seems to be essential to incorporate the vehicle to grid (V2G) electrical vehicles more to the system to prevent frequency-voltage imbalances and to improve power quality. In addition, the removal of the loads/burdens from the system in accordance to the importance degree also has a positive effect if the system does not meet targeted load/burden efficiently.

6.4. Scenario-4

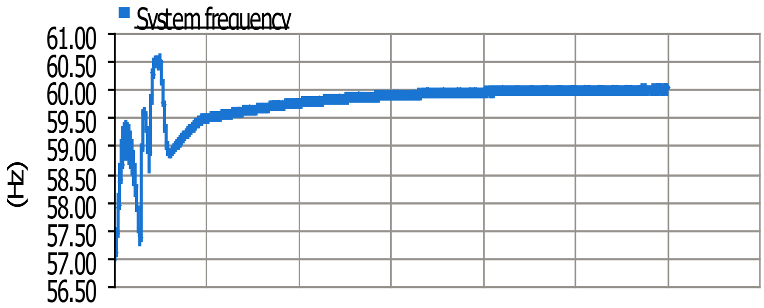
In the fourth scenario, the system were activated by feeding the PV generator, while the synchronous generators were deactivated. When the system was loaded on proper value ranges, the values read from the power distribution curves were as follows: Pg1: 0 kW, Pg2: 0 kW, Ppv: 199,8 kW, Pstorage: -1,7 kW, Pload: 198,1 kW. As seen in Figure 10, the load and production values can compensate one another and the current-frequency values from the system components seem to be at proper ranges.



(a)



(b)



(c)

Figure 10: System variables for Scenario 4 in the Micro Grid Model a) Power distribution graph of the system b) Inverter output of the 3-phase PV current graph c) System Frequency

7. Conclusion

In this study, the system was operated under different states in order to determine the behavior of micro grid in different operating conditions. The system was operated in different conditions by both deactivating and activating the generators, the resultant alterations were analyzed through the current, voltage, frequency and power distribution graphs. The horizontal coordinate of the graphs showing all the results shows the time (t) variable. From the graphs, the results obtained regarding the behavior of micro grid are as follows: For the first scenario, particularly when the power distribution and frequency graphs were analyzed, it was seen that the system is in an ideal performance range. For the second scenario, it was observed that the system's temporary condition instability has lasted longer in comparison to the one in the first scenario, and the reason for this was the demanded load amount has reached closer to the limits of the power generation. For the third scenario, it has taken a long time for the system to transit to the stable state. The system has also been observed to have experienced some difficulties to overcome the demanded load and to have had some serious imbalances on the frequency and voltage values. It has been concluded that the system will not operate properly under these conditions if additional precautions are not taken. For the fourth scenario, it was observed that the system was loaded at the proper ranges and the current-frequency values of the system components were also seen at proper ranges. When all scenarios were examined, it was determined that the frequency range did not exceed the 58-60 Hz band, except for the temporary situation in scenario number four. Therefore, it can be said that the droop control method used in this study was successful.

Increasing the power quality and stabilizing the frequency value for the smart and micro grid systems appears to be a problem. In this study, we have encountered this problem particularly on the second and third scenarios. To come up with a solution for these problems and protect the system against sudden voltage drops, we recommend superconductors, supercapacitors and spare battery groups. In addition, vehicle to grid (V2G) featured electric vehicles are highly recommended due to their provision of mobile energy which are a considerable focus of discussion. Another suggestion of solution would be the removal of the loads from the system in accordance to the importance degree if the system does not meet the targeted load efficiently. That is, to conduct the efficient management of load is recommended.

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