DEPOLAMA, KONTROL EDİLEBİLİR YÜKLER VE AKILLI ÜRETİMİN KULLANILMASI İLE AKILLI ŞEBEKELERDE KAYNAK VE TALEBİN GERÇEK ZAMANLI DENGELENMESİ

REAL TIME BALANCING OF SUPPLY AND DEMAND IN SMART GRID BY USING STORAGE, CONTROLLABLE LOADS AND SMART GENERATIONS.

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ÖZETÇE

Elektrik şebekelerinde, kararlı ve güvenilir bir işletim için kaynak ve talep arasındaki güç dengesi zorunludur. Kaynak ve talep arasındaki fark, birçok elektrik aygıtın hatalı çalışmasına sebep olan frekans sapmalarına neden olur. Üstelik bu durum sistem kararlılığını etkileyerek, 2003 yılında ABD'de meydana geldiği gibi enerji kesintilerine yol açar. Kaynak ve talebin dengelenmesinde, önceden saatlik üretim planlamasının yapıldığı, güç sistemlerinin üretim tarafı kontrolü temel alınmaktadır. Akıllı şebekeler konseptinde, merkezi üretimin baskın olduğu şebeke yapısından sistemin farklı noktalarında bütünleşmiş dağıtık üretimlere kayma söz konusudur. Dağıtık üretim kaynaklarının çoğu sürekli olamayan karakteristiklere sahiptir. Bundan dolayı, geleneksel üretim kaynaklarına benzer olarak bu kaynakların belli bir zaman öncesinde üretim planlamasını yapmak kolay değildir. Bu yüzden, bu yayında gerçek zamanlı bir kaynak ve talep dengelemesi yöntemi önerilmiştir. Bu yöntem, üretim, talep, depolama, piyasa, çevresel koşullar ve diğer gerekli verilerin gerçek zamanlı veriler olarak işlenmesinde kullanılan haberleşme ve ileri düzey bilgi teknolojilerini içeren akıllı şebekeler için uygundur. Bu veriler, akıllı şebekelerde kaynak ve talep dengesinin gerçek zamanlı olarak sağlanması için kararların verilmesinde önemlidir. Buna ek olarak, akıllı şebekelerde cevap talebi ve depolama sistemlerinin avantajları da göz önüne alındığında gerçek zamanlı olarak kaynak ve talebi dengelemek mümkündür. Önerilen yöntem için simülasyonlar DigSilent PowerFactorySimulation ile yapılmıştır.

ABSTRACT

The power balance between supply and demand is essential for reliable and stable operation of power grids. The mismatch between supply and demand causes the frequency deviations which results in malfunction of most of the electrical devices. Moreover, it affects the system stability resulting in system blackouts as that of USA, in 2003. In the smart grid concept, there is a paradigm shift from central generations dominated grid to integrating distributed generations throughout the system. Most of the distributed generations have intermittent characteristic. Due to this fact, it is not easy to schedule their dispatch ahead of time like that of conventional generations. Thus, in this study, a method of balancing demand and supply in real time is proposed. This method is feasible in smart grid as Communication and Advanced Information Technologies are used for real time data exchange about the generation, demand, storage, market, environmental conditions, and other necessary data. Additionally, in smart grid, taking the advantage of demand response and storage systems, it is possible to balance demand and supply in real-time. The simulation is done by the DigSilent PowerFactorySimulation tool for the proposed method.

1. INTRODUCTION

Most of the current electric power systems were built long time before and becoming old. Moreover, they depend on the fossil fuels as the energy sources. The fossil fuels are conventional sources and the reserves are decreasing rapidly [1]. In addition, they emit carbon dioxide gas, which pollutes the environment and causes global warming. The renewable energy resources are important capacity to alternate of the fossil fuels for their durability and environmental friendliness [2]. The next-generation electric power systems integrate these diversified renewable energy resources, storage systems, controllable loads (Electric vehicles, combined Heat Power systems, etc.) and automated and intelligent management systems [3]. As automated and distributed energy network, the smart grid will be described by a two-way flow of electricity and communication and will be able of monitoring everything from generation to consumer [4-6]. It integrates into the grid the benefits of distributed computing and communications to deliver real-time information and allow the instantaneous balance of supply and demand. The management automation and intelligence are expected to present a variety of advantages in terms of intelligence, digitization, flexibility, resilience, sustainability, and customization and makes the power system smart.

Due to the mismatch of supply and demand the stability of the Power system is mostly disturbed. For instance, if the sudden outage of large loads happened in the system, the generations in the nearby may trip due to overspeed (frequency increase). The other area may also be affected because of the outage of the generation system and may trip due to under speed (frequency drop). This leads to cascading outage of the systems, leading to the system blackout.

The other cause of mismatch is the energy consumption profile change from time to time. During peak times the energy demand increases tremendously. Traditionally, during peak times, power system generation reserves are used to compensate the mismatch.

Moreover the generation from renewable energy resources vary with time as their resource is intermittent. In spite of the potential of renewable generation, it makes difficulties the overall balance of supply and demand. Distributed generation—for example, small-scale renewable sources which are owned and operated by customers—complicates the condition by causing the mismatch between supply and demand.

These problems are envisioned to be handled by smart grid through demand response and storage systems. In this study a method to adjust the mismatch in real time by using all the available resources (storages, controllable loads, smart conventional generations and distributed generations) is proposed. By using the DigSilentPowerFactory simulation tool the effectiveness of the method is verified.

2. OPTIONS FOR DEALING WITH IMBALANCES

Electricity demand fluctuates continually from time to time. In the traditional power systems, the problem of balancing mismatch between generation and load is tackled, especially by purchasing power from another state, starting up old power plants, building new power plants which are costly. In some cases Load shading is implemented by removing some loads from the system. If these measurements are not the working, the system may go to black outs with high customer impact.

In a smart grid by incorporating a communication, computing and control on the power grid, we can include large-scale renewable sources. Additionally, with emerging storage Technologies and by providing control signals to loads we can match supply and demand in real time [7]. This improves energy efficiency, reduces consumptions and increases the performance and reliability of transmission and distribution networks.

2.1 Storage

Traditionally, energy storage needs have been met by the physical storage of fuel for fossil-fuelled power plants, by keeping some capacity in reserve and through large scale pumped hydro storage plants.

But now the power landscape is changing dramatically with a move to 'fuel-free' power, mainly in the form of wind and solar photovoltaic (PV). This shift to renewable sources is good for the environment and sustainability. Since there is no fuel to store, the grid must adapt to store electrical energy efficiently after it is generated [8]. Wind and solar power plants generate energy intermittently and with variable output. These new sources may be located anywhere on the grid, perhaps close to the load centers they serve, dispersed across the network, or even in remote locations.

Increasing the use of traditional methods of building storage capacity into the grid by providing spinning reserve, which uses fossil fuels would reduce the very environmental benefits that renewable power sources are intended to bring. One solution to the problem of balancing mismatch between supply and demand is the storage system. The approaches of storage system vary from underground compressed air to flywheels to novel battery materials. Moreover the storage provides ancillary services such as high-cost frequency regulation, black start capacity and spinning reserve. The wind and solar off peak generations can be shifted by using the storage. The availability of storage system makes the integration of electric vehicles easy in smart grid without expanding the existing distribution system [9-10]. It also supports the power system during islanding operation.

Among the above mentioned advantages of storage, the balancing of the mismatch between supply and demand and reducing the ramping impacts caused by renewable generations and the load variation is demonstrated in this study by using DigSilent simulation tool [11].

2.2 Controllable Loads

In the next step of the smart grid, consumers can make more informed decisions about their energy consumption, controlling both the timing and amount of their electricity use. This happens, through demand response. Demand response encourages a shift of energy demand of end consumers. It is also about matching use to the available generation like for example, if there is a peak in consumption, but more generation from renewable is available, as a result there may be a desire to increase the consumption during the peak. The participation of the end consumers is a response to factors such as incentive pricing, new tariff schemes, greater awareness and an increased sense of responsibility. The the participation may involve either active behavioral changes or passive responses, through the use of automation [12-15].

On the other hand the increasing levels of control by utilities will allow automated demand response programs, by ensuring load shed and enabling utilities to build this capacity into markets as a resource. In this study the loads that are allowed by the customers to be controlled by the utility are assumed. By using intelligent devices the customers will allocate some of their load (like air conditioning systems) to be used for regulation of the power system without affecting their comfort. By doing so, the customers receive rewards from the utility. The customers specify also the time duration the loads are allowed to be controlled. These loads are connected or disconnected by the utility based on need to regulate the system or match the demand and supply. The information about the real time situation of these controllable loads are accessed through AMI (Advanced Metering Infrastructure) and stored in the load data server. The controller follows any change in the load though the data server. The change on the loads (connecting or disconnecting) is also updated when the actions are taken by the controller.

2.3 Smart Power Generatıons

In smart grid the current power systems, which consist of mainly conventional power plants need to be complemented with dispatchable, dynamic capacity to overcome the problem of mismatch of balance and demand. In the form of fast starts, stops, and load ramps there must be the capability for frequent system balancing. The power system of the future will require

a capacity which corresponds to at least 50% of the installed intermittent power capacity [16]. The smart power generation is characterized by operational flexibility, fuel flexibility and energy efficiency.
They are expected to supply power to the grid in one minute from start-up and reach full load in five minutes. They are designed to start and stop very fast without creating maintenance problems. This smart generation is expected to have ancillary services and grid support. They are expected to have very high plant availability, plant reliability and starting reliability.

To be low carbon power plants, the smart generations must have the continuous option of the most feasible fuel, including solutions for liquid and gaseous fuels as well as renewable. Smart Power Generation plants based on multiple generating units are expected to be more fuel efficient than large power plants.

Generally Smart Power Generation is expected to enable the complete power system to operate in the most cost efficient way with the lowest possible carbon emissions, and the maximum utilization of renewable energy such as wind and solar power. Moreover, Smart Power Generation secures the electricity supply by balancing the system even during severe wind variations and contingency conditions. In this paper smart power generation is considered in supporting the balancing of the system.

3. THE PROPOSED METHOD

Figure 1 shows the proposed method for the real time control of the active power in the smart power system. One of the main characteristics of the smart grid is the availability of suitable communication and information infrastructures which enables the flow of data and information among the components of the smart grid. In addition the sensors and data acquisition devices that are laid out through the system makes the system more aware of each and every condition in the system. Consequently, by using the above mentioned advantages of the smart grid it is possible to manage the mismatch between the active power generation and consumption in real time which is not possible in the traditional power system.

In the proposed method the load data are collected from the system through AMI. The AMI is capable of two way communication of information between the consumer and supply. The load is obtained from the server of load data which is updated in realtime. These real time data may also include the size of the controllable loads like electric vehicles, water heaters, dryers, etc., which can be used for adjusting the system in case of the mismatch between supply and demand. The consumers are assumed to allow some of their loads for the system regulation's purpose in reply to the incentive through demand response. Secure and reliable communication system has to be used for exchanging data and commands between operating systems and the AMI.

The controller starts by updating the data in real time. Then the total generation and total demand at the particular time is calculated by adding the generation and total demand at the real time. The total generation includes the real power at that particular instant from conventional generations, distributed generation and from the storage systems that are supplying power to the system (discharging). The total load included the non controllable and the controllable loads connected to the system at that time instant.

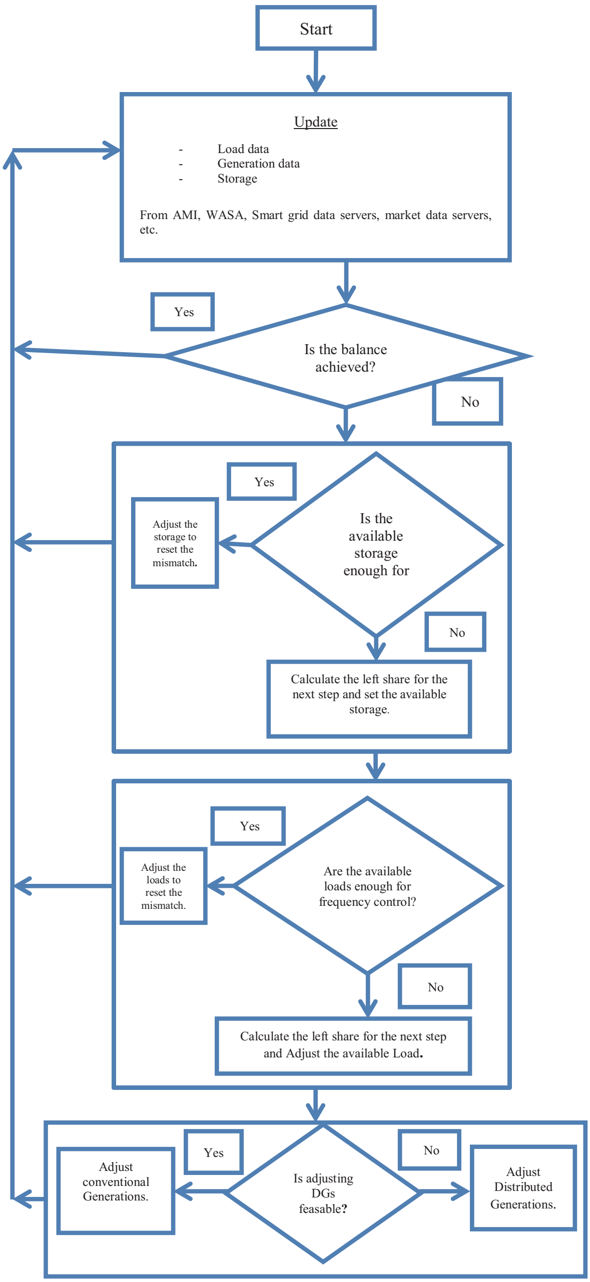

Figure 1: The flow chart of the proposed algorithm

$$P_{GT}(t) = \sum_{i=1}^{n} P_{DG}(t) + \sum_{j=1}^{m} P_{StorC}(t) + \sum_{k=1}^{g} P_{Conv}(t) \quad (1)$$

$$P_{Load}(t) = \sum_{l=1}^{f} P_{LC}(t) + \sum_{r=1}^{s} P_{LNC}(t) \quad (2)$$

$$\Delta P(t) = P_{GT}(t) - P_{Load}(t) - P_{loss} \quad (3)$$

Where: $P_{GT}(t)$ *is a Real Time Total Generation in MW;* $P_{DG}(t)$ *is Real Time Power from Distributed Generations in MW;* $P_{StorC}(t)$ *is the power supplied to the grid from storage systems in real time in MW.* $P_{Conv}(t)$ *is the power from conventional generation in real time in MW;* $P_{Load}(t)$ *is the total load on the system in real time in MW;* $P_{LC}(t)$ *is the total controllable loads in real time in MW;* $P_{LNC}(t)$ *is the total non-controllable loads in real time in MW;* P_{loss} *is the power loss in the system in MW.*

The mismatch is then calculated as shown in the equation (3). If the mismatch between supply and demand is within the allowable range, so that the system frequency and stability is not affected, the controller updates the data after the specified time delay (i.e. The data are updated at regular interval to avoid system ramping). If the mismatch is not within the allowable range the controller has to act to adjust the mismatch. According to the system, to adjust the mismatch all the available resources may be used or some of them may be used depending on the size of mismatch.

For instance considering the sequence shown in the flow chart (Figure 1), first the available storage systems are used to absorb the mismatch power, then the controllable loads and finally the smart generations are used. If, for example, the load increase or generation decrease, the balancing act is conducted as shown in the equations 4 to 6. For the case when the mismatch is large enough and exceeds the available storage resource, the controller starts with storage and goes to the controllable loads finally to the generations. If the available storage resource is large enough to absorb the mismatch, the controller goes to updating the data for the next step in the specified interval. Otherwise the storage takes its share and passes the left mismatch to the controllable load or generations based on the available resource that has the capability to adjust the mismatch.

$$ShareS(t) = \Delta P(t) - StoredP(t) \quad (4)$$

$$ShareL(t) = \Delta P(t) - StoredP(t) - P_{LCD}(t) \quad (5)$$

$$ShareG(t) = \Delta P(t) - StoredP(t) - P_{LCD}(t) - P_{SG}(t) \quad (6)$$

Where; $ShareS(t)$ *is the share of the mismatch in MW that is absorbed by storage;* $StoredP(t)$ *is the stored power in MW that is used to adjust the mismatch;* $P_{LCD}(t)$ *is the controllable load in MW that is used to adjust the mismatch;* $P_{SG}(t)$ *is smart generation power in MW that is used to adjust the mismatch.*

When the generations are used to adjust the mismatch in addition to the conventional generations and the distributed generations can also be used if it is found feasible (see the flow chart of Figure 1). The use of distributed generation for adjusting can be applied when the penetration level of the distributed generations is very high and the smart generations are not sufficient enough to regulate the system. However the DGs are derated for this purpose so that they can be used as that of conventional generations. This has its own disadvantage of reducing the power that is got from DGs.

4. SIMULATION AND RESULTS

The network shown in the Figure 2 is part of the Ethiopian Electric Power grid. And islanded mode is considered to test the proposed algorithm. In addition, storage and controllable loads are added in the network (in the original system, there is no storage system). In this simulation the variation from DGs is considered, however, it is also possible to consider the variation of the load or combination of the two to simulate the mismatch. In the simulation, the variation from DGs is considered as shown in the Figure 3. The power from conventional generation is fixed to 36 MW and generation of DGs (wind power) varied from 35 MW to 60 MW while the Load is fixed to 71 MW. The installed capacity of the storage system in the power system is 35 MW. Due to the variation from DGs the mismatch is introduced into the power system as shown in Figure 3. The controller collects this data automatically from the sensors laid throughout the system and makes decision in real time. The controller first chooses the feasible resource to handle the mismatch. For example, if sufficient storage is available according to the algorithm shown in Figure 1, the controller gives a command to the storage system to handle the mismatch.

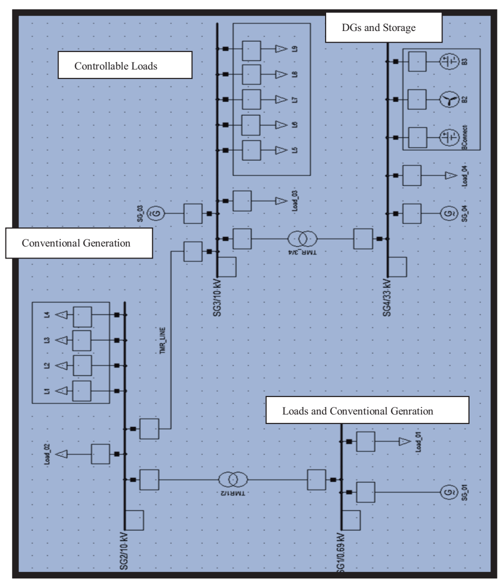

Figure 2: The DigSilent Network model to test the proposed algorithm.

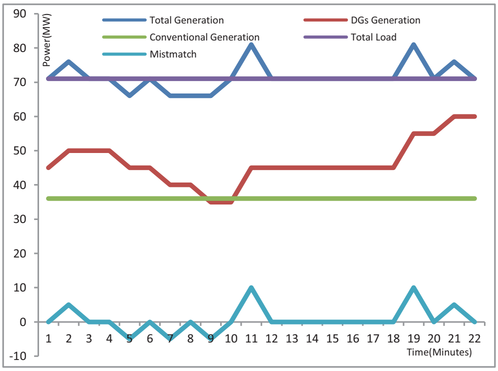

Figure 3: Generation from DGs, Generation from Conventional Power Power Plants, Total Generation.

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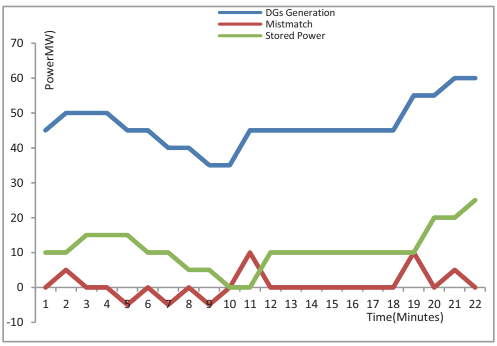

Figure 4: The storage system tracks the variation from the DGs and resetting the mismatch.

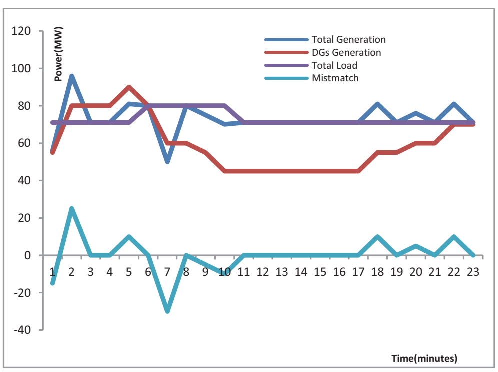

Figure 5: Generation from DGs, Generation from Conventional Power Power Plants, Total Generation.

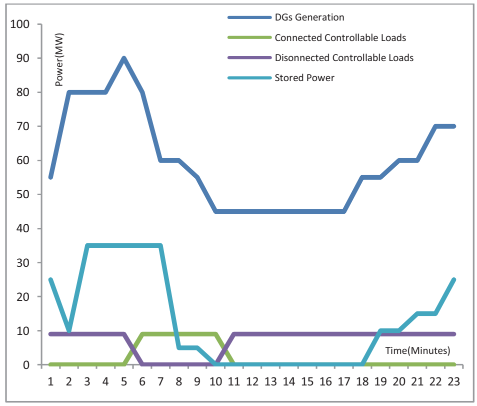

Figure 6: Storage, Controllable load and smart generation are involved in adjusting mismatch.

Consequently, as shown in Figure 4 the storage system tracks the variation from DGs by storing power when there is excess generation from DGs and supplying power to the network when the DGs generation decreases.Similarly, in Figure 5, the DGs varied from 45 MW to 90 MW. The storage capacity is again 35 MW and the controllable loads in the system that are allocated for handling the mismatch is considered to be 9 MW. In this case, the mismatch cannot be handled by using only the storage system. If the storage resource is full or empty the controller searches on the load data server the loads that are allocated to be used by the controller (these loads can be from demand response or the loads that customers allocate based on the intensive received; for example electric vehicles that are charging or discharging). If the mismatch is not handled either by storage or the controllable loads the controller uses either the smart generation systems or load shedding (even the non- controllable loads) to protect the system from further stability problem or black out. In the Figure 6 it is shown that in addition to storage resource, controllable loads are used to handle the mismatch.

5. CONCLUSION

In this work it is proved that the smart grid enables the power system to be more efficient and stable, especially when renewable energy systems which are intermittent by their nature are integrated into the system. In smart grid it is possible to integrate renewable energy systems and handle the mismatch between demand and supply by controlling the system in real time. This requires the access to data from generations, loads, storage systems, energy markets, etc. This is possible in smart grid due to communication, information and sensor infrastructures laid throughout the electricity network. In this work it is demonstrated that the system mismatch can be handled even if the ratio of the renewable energy resources in the system is very high. This method is also very important when there are less number of synchronous machines in the network and the inertia of the system is low. The proposed method is also applicable for the variation of the load or any other contingency conditions that disturb the balance between demand and supply. The order of choice of the controller whether to use storage, controllable loads, smart generations or load shading depends on the factors like available capacity, environmental data, market data, location of the resources, etc. This requires optimization to get a feasible and efficient solution. The work on this part is in progress.

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