Real Time Active Power Control in Smart Grid

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A*bstract* - A 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. For decades the balancing of supply and demand was based on generation side control of power systems through ahead of time generation dispatch scheduling. The smart grid is being used today to describe technologies and methods that automatically and rapidly isolate faults, restore power, monitor demand, and maintain and restore stability for more reliable electric power. Thus, in this study, a method of controlling active power (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. These data are important in making decisions about real-time supply and demand balancing in the smart grid. 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 Power Factory simulation tool for verification of the proposed method. In addition to an electric network modeling part of the simulation tool, the DigSilent Programming Language (DPL) feature is used for coding the decision making program.

Keywords: Demand and supply; Demand response; DigSilent PowerFactory; Real time control; Smart grid; Smart generation; Smart grid domains.

I. INTRODUCTION

Most of the current electric power systems are becoming old as they are constructed before many years. Moreover, they use 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 [2,3]. 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 [4-6]. In recent years, the trend towards renewable energy sources in distribution systems has been significantly increased. Therefore, new approaches seem necessary to model the most appropriate location of these resources [7]. 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 [8-11]. 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.

Due to the mismatch of supply and demand the stability of the Power system is mostly disturbed [10-12]. 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 power system in 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

978-1-5386-2095-3/17/$31.00 ©2017 IEEE

blackout.The other cause of mismatch is the energy consumption profile change from time to time. Moreover the generation from renewable energy resources vary with time as their resource is intermittent. Distribution systems, which play an important role in the power system, need flexible and intelligent planning methods to meet the demand for the future [13,14]. 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. 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. 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, reserves, controllable loads, smart conventional generations and distributed generations) is proposed. Optimal planning of the reserve contributes to the stabilization of supply and demand [15]. By using the DigSilent PowerFactory simulation tool the effectiveness of the method is verified.

II. THE PROPOSED METHOD

Figure 2 shows the proposed method for the real time control of the active power in the smart power system. In the proposed method the load data are collected from the system through Automatic Metering Infrastructure (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 real-time.

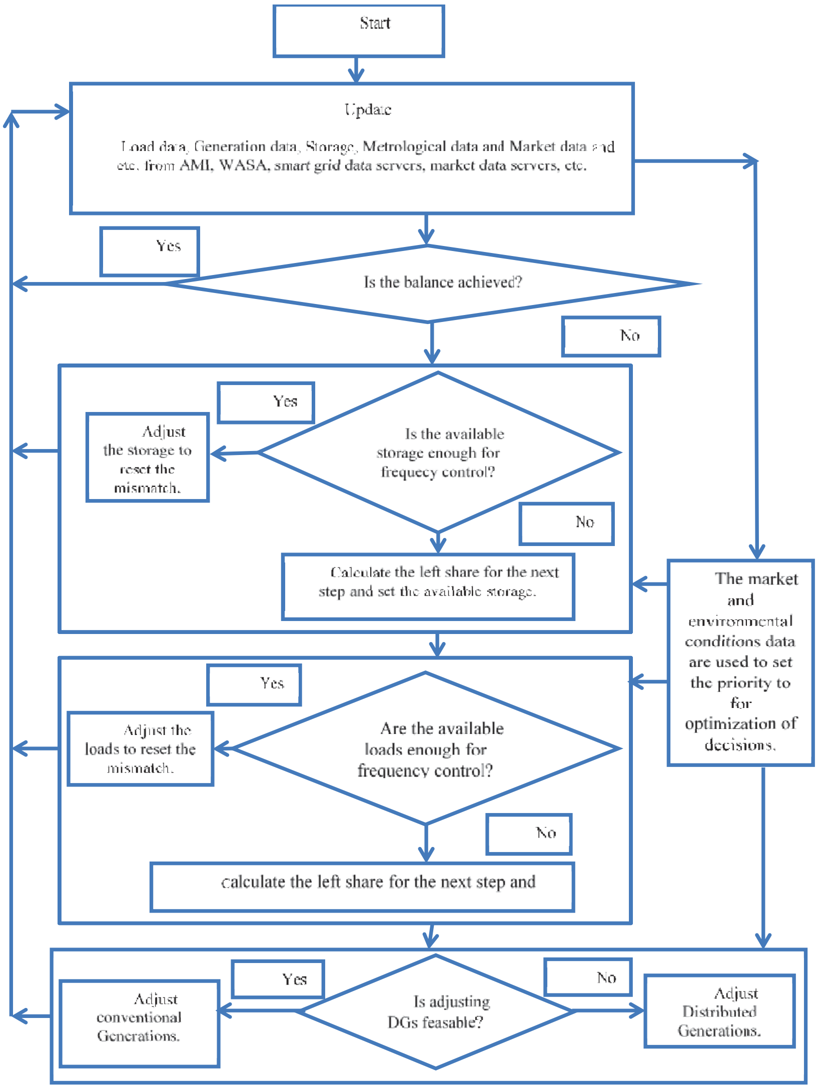


Figure 2: The flow chart of the proposed algorithm.

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 load 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 [12].

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

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

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

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. $P_{Conv}(\mathrm{t})$ 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; $\mathrm{P_{loss}}$ 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 (Fig.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)-(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 [16].

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

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

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

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 Fig. 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 de-rated 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.

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.

III. SIMULATION AND RESULTS

The network shown in the Fig. 3 is part of the Ethiopian Electric Power grid. An 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 Fig. 4(a).

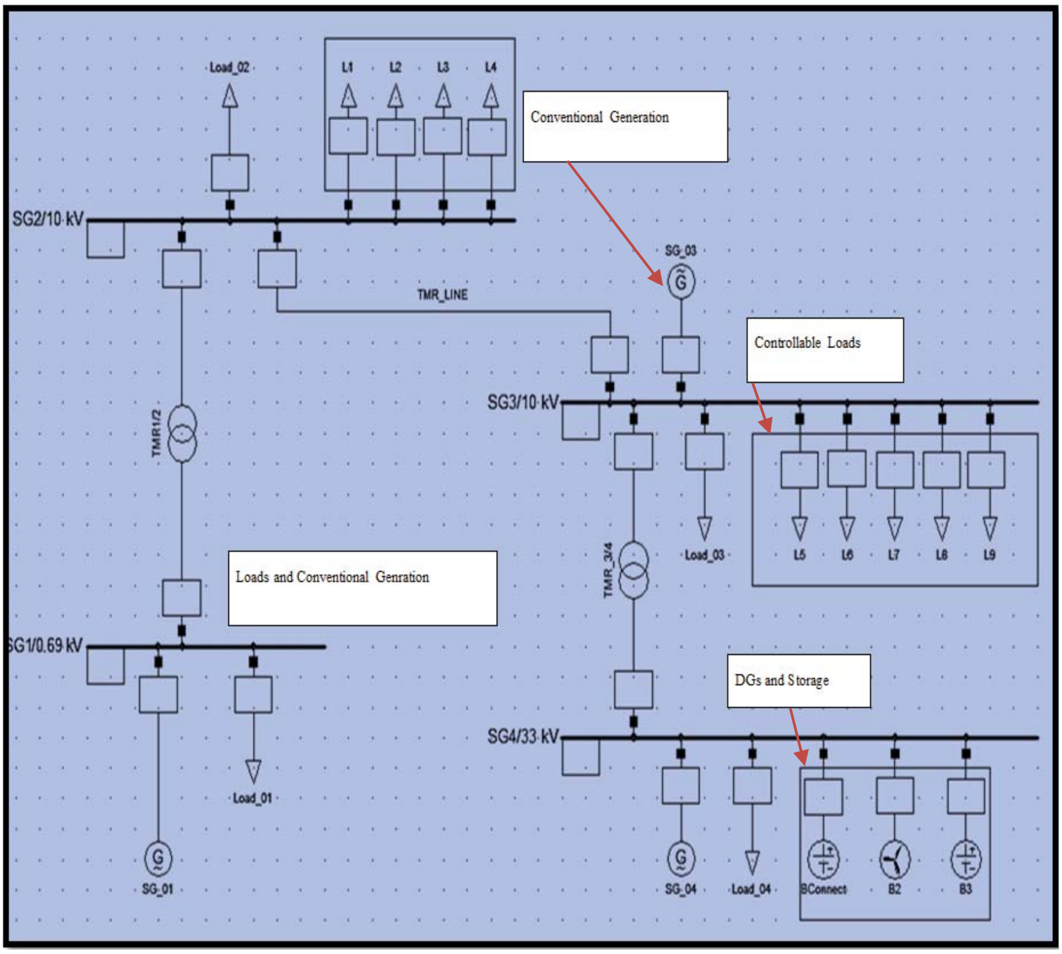
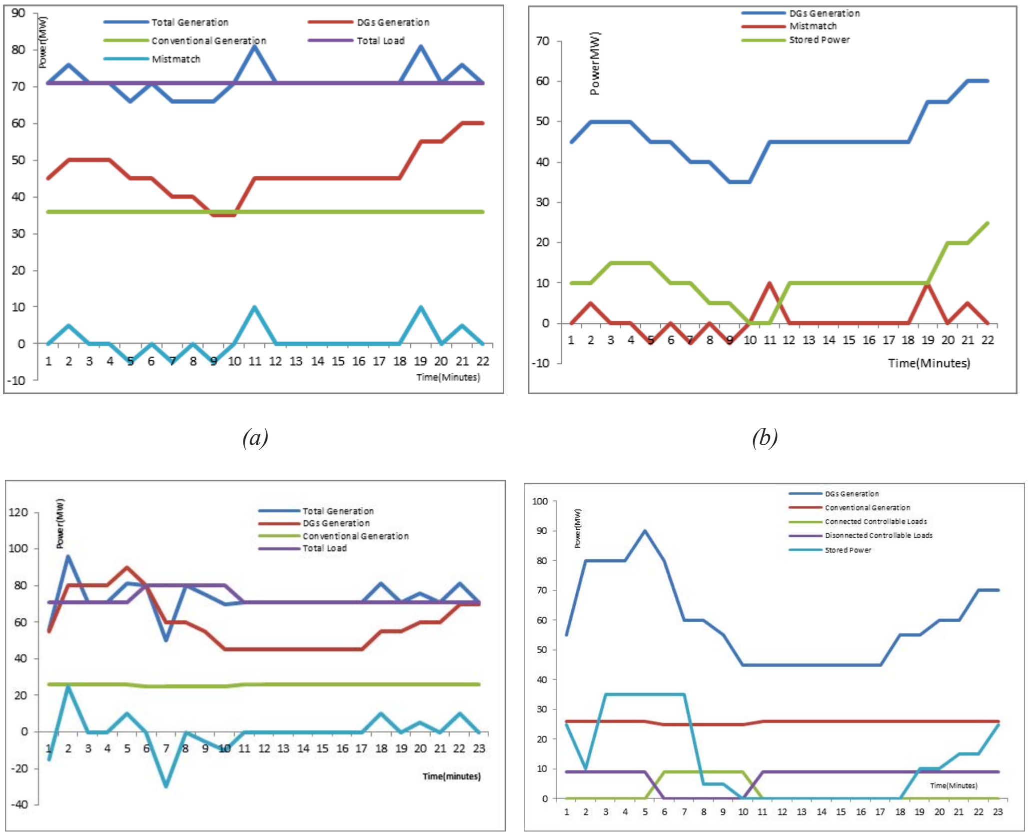


Figure 3.The DigSilent Network model to test the proposed algorithm.

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 Fig.4 (a).

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 Fig. 2, the controller gives a command to the storage system to handle the mismatch.

Consequently, as shown in Fig. 4(b) 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 Fig. (d), 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). Moreover, in this case the mismatch is not handled either by storage or the controllable loads, as a result the controller used the smart generation systems to protect the system from further stability problem. In the Fig. 4(d) it is shown that in addition to storage resource, controllable loads and smart generation are used to handle the mismatch.



(a) *(b)*

(b) *(d)*

Figure 4. (a) Generation from DGs, Generation from Conventional Power Power Plants, Total Generation. (b)The storage system tracks the variation from the DGs and resetting the mismatch.(c) Generation from DGs, Generation from Conventional Power Power Plants, Total Generation.(c) Storage, Controllable load and smart generation are involved in adjusting mismatch.

IV. 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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