FREQUENCY CONTROL IN CIGRE LOW VOLTAGE DISTRIBUTION NETWORK WITH SIGNIFICANT AMOUNTS OF INVERTER BASED GENERATORS

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ABSTRACT

Maintaining demand side supply and regulating frequency in power networks are the prime requirements of the modern power systems. The frequency of the power system deviates from its nominal value if there is mismatch between power generation and the consumption. If the active power demand is higher than the active power production in the network, the frequency decreases and vice versa. The increase or the decrease in the frequency can be compensated by balancing the generation and load demands. This is normally done by allocating reserve units or by using inverter based generators such as Battery Energy Storage Devices (BESDs). The main focus of this paper is to control the frequency of the network by providing/absorbing the required/extra amounts of the power by BESDs. The work is done on a simple network and simulations are carried out by using DIgSILENT power factory software version 15.0. The procedure of modeling BES which should operate as Battery Energy Storage equipped Static Compensator (BES-STATCOM) developed in DIgSILENT power factory is also described in this paper.

Keywords: Battery Energy Storage Devices (BESDs), Frequency control, Battery Energy Storage equipped Static Compensator (BES-STATCOM, CIGRE network

1. INTRODUCTION

It is the prime requirement in power systems that the Load-generation must be corrected within short duration; otherwise it might leads to the power line frequency to deviate from the rated value (e.g., 50 Hz in this study). Large deviations in the frequency of the power network cause the threats to the stability and the security of power systems and might cause permanent damage to the equipments [1], [2]. Due to this reason balancing between generation and load in order to regulate the frequency at the nominal value has gained a vital importance. Several control approaches have been reported in the literature to serve the goal. Some of the power system uses Automatic Generation Control (AGC) technique which issues signals in order to control the reserve units and minimize Area Control Error (ACE), which includes both frequency deviation and unscheduled tie-line power flows [3], [4]. The spinning reserve is also used in order to regulate the frequency. The generators which are used as spinning reserve units automatically increase their outputs when supply is suddenly lost [3]. Furthermore, many generators are equipped with speed governors which adjust their speed depending on the frequency response of the network [5], [6]. The other techniques which are used for this purpose use exciters and Power system stabilizers (PSS) [7]. The problem in such kind of techniques is the time for the switching of the units from off-mode to on-mode. The ESDs are becoming popular for the load-generation balancing in the networks due to their faster response because of the power electronics interfaces as compared to the conventional reserve units such as synchronous generator based reserves. The ESD can store surplus power produced in the grid and can release the energy into the electricity grid in the case of generation deficit. This property of ES systems can smoothen the short term as well as long-term variations in the power caused by the load variations and behaves like power system balancing and reserve units. The main idea of the study proposed here is about the frequency stability in the CIGRE low voltage distribution network (i.e. developed European CIGRE working group experts) as shown in Fig. 1. This is done by matching load-generation balance in the network shown in Fig. 1. The entire study about the frequency stability within the CIGRE network is not performed here but the CIGRE network shown in Fig. 1 is split into a very simple network comprising finite grid (i.e. a synchronous generator with the active power capability of 30 kW), one battery unit and a load. This is done in order to show the detailed procedure about the control of frequency within the power networks and same procedure is proposed for the frequency stability within the CIGRE low voltage network. The load-generation matching in this paper is done by using 30 kWh BES unit which is modeled as BES-STATCOM for this study. The regulation of the network frequency by using ESDs has already been implemented in several power systems and is available in the literatures.

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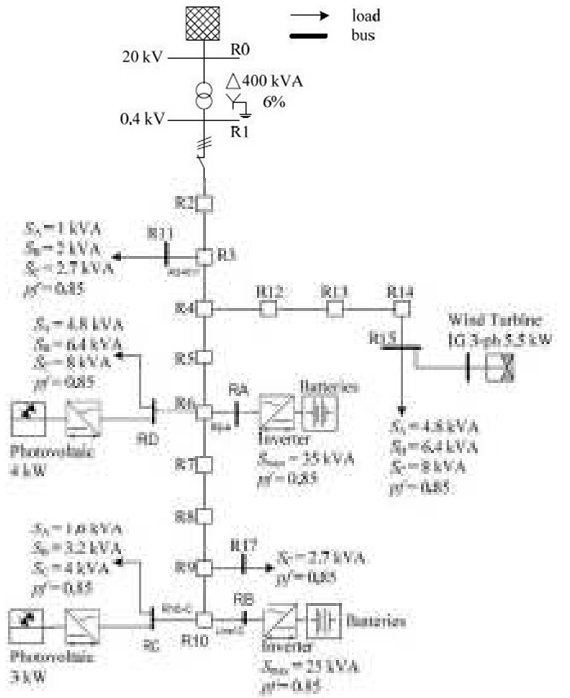

Fig. 2 The single line diagram of CIGRE LV distribution system

The main focus of this paper is to describe the new way of modeling and control set up of the ESD which can operate as BES-STATCOM. The short description about the modeling and the control set up of BES-STATCOM is presented by the author in [8]; this paper gives the detailed description about the development of control system. The developed control system is validated by showing simulation results in this paper. The simple network which comprises a constant impedance load of 30 kW, a synchronous generator which has a capability of providing 30 kW active power and BES unit of 30 kWh energy capacities is used for this study. The modeling and control set up is done in DIgSILENT. The block diagram of the network under the research study in this paper modeled in DIgSILENT is shown in Fig. 2.

It can be seen in Fig. 2 that a battery operating as ESD is connected at DC bus bar of 0.71 kV. The power output of ESD is DC; therefore, a PWM converter is used to transform power into AC from the DC. The DC terminal of the converter is connected at DC bus bar whereas its AC terminal is connected at AC bus bar of 0.4 kV through a series reactor as shown in Fig. 2. A series reactor is used to add some reactance in the network for this study. A synchronous generator of 30 kW operating at unity power factor and a balanced load of 30 kW are also connected at the AC bus bar as shown in Fig. 2.

This paper is organized as follows: Section 2 gives the detailed description about the modeling and the development of the control set up for BES-STATCOM in DIgSILENT power factory software. Section 3 presents the simulation results in order to validate the developed controller. Finally, the conclusion of the paper is presented in section 4.

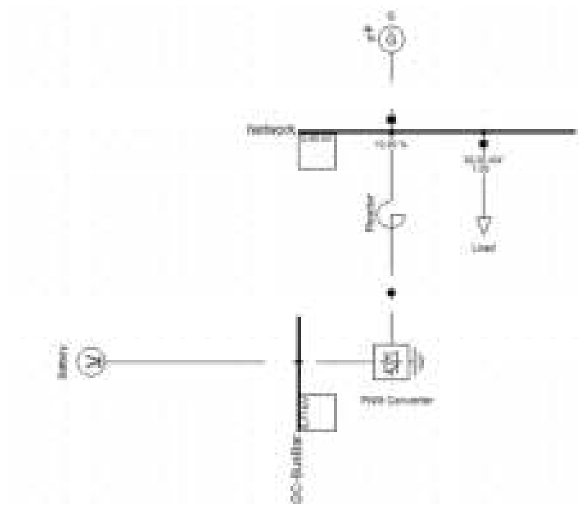

Fig. 3 The block diagram of the network modeled in DIgSILENT

2. METHODOLOGY AND THE DEVELOPMENT OF THE CONTROL SYSTEM FOR ESD

Most of the methods used for battery modeling are complex and time consuming [9-13]. The need for an accurate and complete battery model is dependent on the field of its application. A wide range of battery models are used for simulation studies in various literatures like mathematical, electrical or electrochemical models [14]. The BES-STATCOM in this paper is modeled using a thevenin equivalent representation of the Lithium ion battery and is shown in Fig. 3 [15], [16].

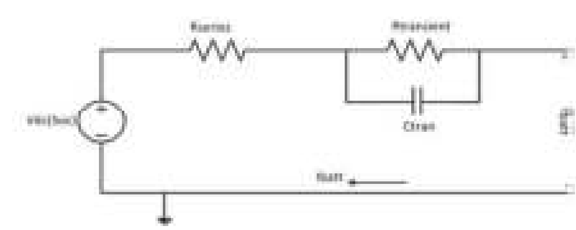

Fig. 4 Electrical model of the Lithium ion battery [15], [16]

This model consists of an ideal voltage source in series with an internal resistance and a parallel RC network. The specifications of a single cell of lithium ion battery are shown in table 1 and are taken from [17]. The built-in model of an infinite DC voltage source is used for the modeling of the BESS in DIgSILENT software [18].

In order to obtain desired amount of power output from the ESD, 170 cells have been connected in series and 6 cells in parallel. The total capacity of ESD in this paper is 42 Ah (i.e. 7 Ah* number of parallel connected cells).

The maximum and minimum voltage of the battery is 714 V (i.e. 4.2* number of series connected cells) and 425 V (i.e. 2.5* number of series connected cells) respectively. As the power output of the battery is DC, an inverter is used to convert DC power into AC power. The PWM inverter is modeled in DIgSILENT according to the reference [19].

Table 1 Battery Specifications for a single cell

Parameter	Value
Capacity	7 Ah
Nominal Voltage	3.7 V
Maximum Voltage	4.2 V
Minimum Voltage	2.5

In order to obtain RMS simulation results and controlling the charge/discharge rate of the ESD, it is necessary to develop the DIgSILENT Simulation Language (DSL) model of the battery and its controller. The composite model made in DIgSILENT, showing signals coming in out of respective blocks is shown in Fig. 4.

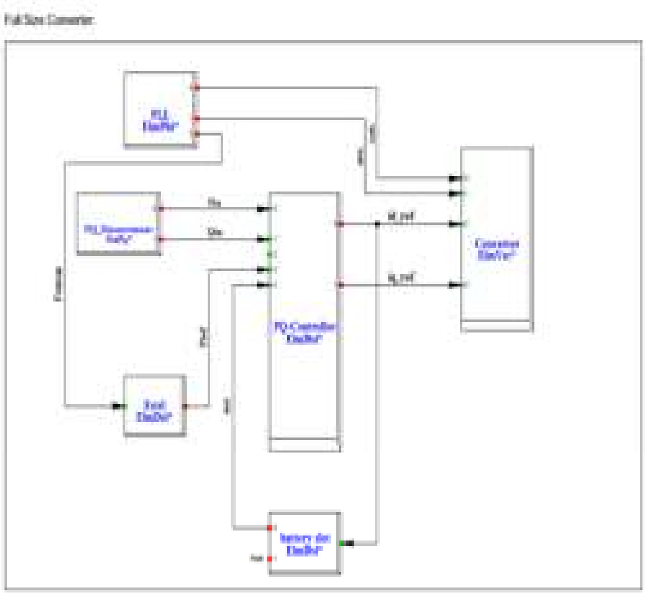

Fig. 5 The composite frame model of BES-STATCOM

There are different blocks used in this model, some of them are measuring bocks and others are DSL models. The blocks showing "Sta, ElmPhi, and ElmVsc" representations are the measuring blocks and the blocks showing "ElmDsl" require DSL modeling. The PLL block is used to measure the angle and the frequency of grid voltage and send the respective signal to the converter and the frequency controller. The DSL model of the frequency controller is shown in Fig. 5. This controller compares measured and reference frequency and sends the error signal to PI controller to generate Pref.

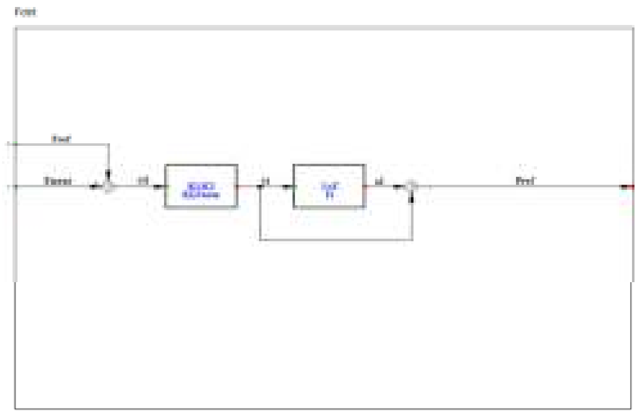

Fig. 6 The DSL model of frequency controller

The block representing PQ measurement shown in Fig. 4 is used to measure active and reactive power at the AC bus. The active and reactive power 'Pin' and 'Qin', the active power reference 'Pref' sent by the frequency controller and battery State Of Charge 'SOC' are the inputs to the PQ controller slot as seen in Fig. 4. Its outputs are active current reference (idref) and reactive (iqref) currents references. These currents references will be sent to current controller which will decides the duty cycle for the switches used in the converter [20]. The DSL model of PQ controller is shown in Fig. 6. The active current reference (idref) is sent to the battery slot (see Fig. 4) where it will be integrated in order to get the charge. Due to safety concerns the battery SOC is limited within 20-95% in order to avoid damage of the battery and to preserve battery life, [16]. The details about the DSL modeling of battery slot and the explanations about the DSL model of PQ controller shown in Fig. 6 are presented in [8].

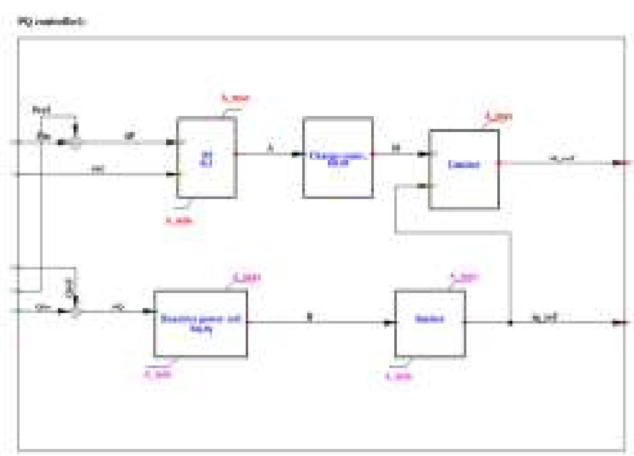

Fig. 7 The DSL model of PQ controller

3. SIMULATION RESULTS

In the normal operation, the load active and reactive power requirements are delivered by a synchronous generator. Active power injection by the BES-STATCOM is zero in this condition and the power system operates at its nominal frequency and voltage limits. Since synchronous generator can only provide 30 kW, if the load is increased more than this limit then there will be problem with the network frequency unless it is supplied by the battery. To analyze the power system frequency response of the distribution network shown in fig. 2, a step increase/decrease in the active power of a system load is simulated here. When the demand is increased, the system frequency decreases. A step load increase of 90% is applied at the time equal to t=40 sec on the system load. The load with step applied becomes 57 kW in this condition. The synchronous generator is delivering 30 kW and remaining 27 kW power is supplied by the battery. The PI controller of the active power control loop shown in fig. 5 generates a current reference at 40 sec in this condition. When the battery is discharged down to 20%, the current output of this PI controller reaches to zero. The output of the PI controller is sent to the charge controller which controls the charge/discharge rate of the battery. The study of the same battery which is used in CIGRE low voltage distribution network in the case of different charging rates is given in [8], [21]. The battery is delivering current to the load at full charging rate (i.e. 1 C rate) in this condition. The current delivered by the battery in this case is shown in Fig. 7.

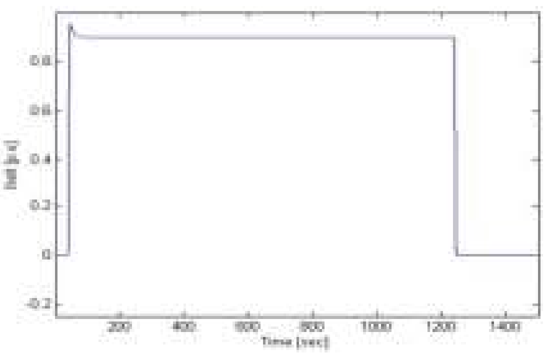

Fig. 8 Battery current at full charging rate

This current as shown in Fig. 7 is sent to the battery slot where it is integrated to obtain the charge.

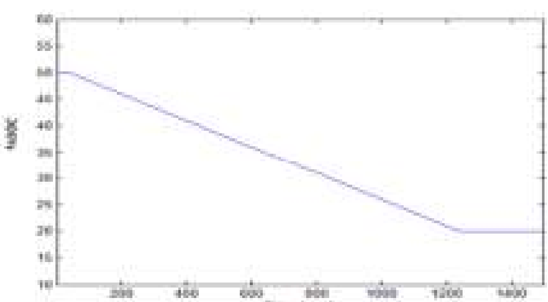

Fig. 9 percent SOC of battery

The discharge capacity of the battery depends on how fast battery is discharging. Higher the discharging rate, lower the time required for the battery to be discharged and vice versa [22], [23]. The SOC of battery with the above load step is shown in Fig. 8.

The battery charge/discharge rate is defined in the PQ controller shown in Fig. 6. Discharging of battery starts at 50% because this limit has been set as an initial condition for charge/discharge in the DSL model of the battery [8], [21]. The frequency of the network with the above load step applied is shown in Fig. 9.

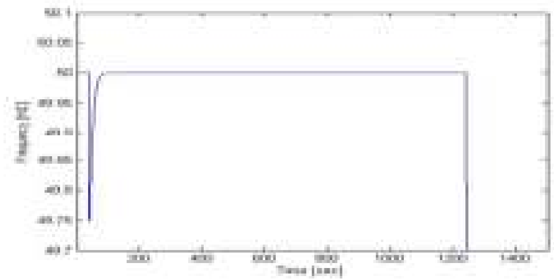

Fig. 10 Frequency of the network

As seen in Fig. 9 that frequency decreases at 40 sec due the increased load demand and is controlled by the ESD in a short period by injecting desired amount of the power. When battery is discharged down to the limit of 20%, it has no more power to supply the load. The frequency in this case when battery has been fully discharged reduces drastically and the system enters into unstable condition as shown in Fig. 9.

Again a load step of -90% is applied at time, t=40 sec on the system load. The load demand with this step applied decreases and becomes 3 kW. The synchronous generator of 30 kW is delivering 3 kW to the load and remaining 27 kW power of the generator is used to charge the battery. The PI controller responsible for active power loop of PQ controller shown in Fig. 6 generates a current reference at 40 sec in this condition.

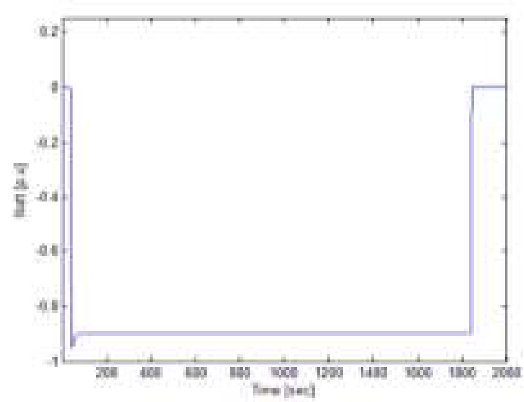

Fig. 11 The current flowing to charge battery units at full charging rate

When the battery is charged up to 95%, the current output of this PI controller reaches to zero. The output of the PI controller is sent to the charge controller which controls the battery charging rate. The battery charges at full charging rate (i.e. 1 C rate) in this condition. The current going into the battery in order to charge it in this case is shown in Fig. 10.

The battery SOC and the network frequency are shown in Fig. 11 and Fig. 12 respectively. As seen in Fig. 11 the battery is charged up to 95% in half hour (i.e. 1800 sec) because initial SOC of a battery is at 50% in the beginning of simulation results.

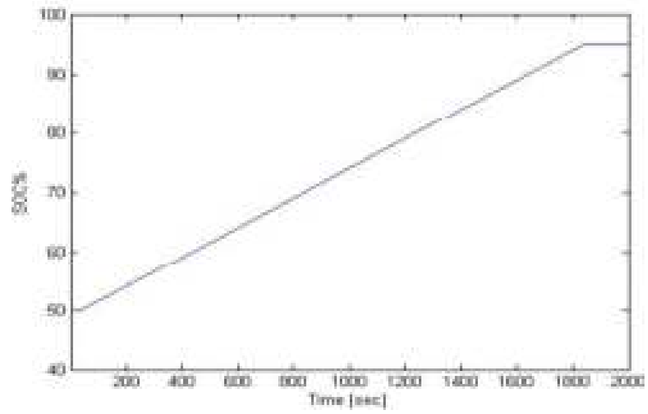

Fig. 12 Percent SOC of ESD

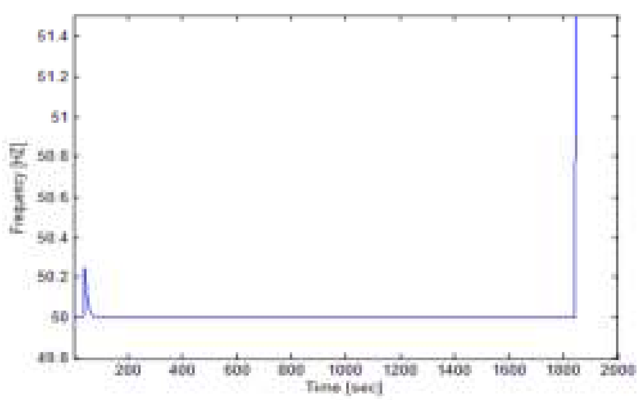

Fig. 13 Frequency of the network

It can be seen in Fig. 12 that frequency of the network increases at 40 sec due the decreased load demand and is controlled by the battery in a short period by absorbing extra amount of the power supplied by the synchronous generator. When battery is charged up to the limit of 95%, it cannot absorb more power; therefore, frequency of the network is increasing very fast and the system enters into unstable condition.

4. CONCLUSIONS

The study about the constancy of the frequency of power system has been carried out in this paper. The study is performed on a very simple network and these concepts are proposed for the frequency stability within the CIGRE low voltage distribution networks and other networks like that. The development of BES-STATCOM controller for ESDs has been described here and the developed controller has been validated by using simulation results. Different scenarios such as load reduction or generation deficit have been studied in this paper. It has been proved with the help of the simulation results that the ESDs in all the conditions have successfully restored the frequency of the network within a short duration. The study about the islanding, voltage and the frequency control in islanded portion of the CIGRE low voltage distribution network will be done in the future.

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