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New adaptive reclosing technique using second-order difference of THD in distribution system with BESS used as uninterruptible power supply

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ABSTRACT

This paper proposes a new adaptive reclosing technique that considers the battery energy storage system (BESS) in a distribution system. The proposed technique focuses on operation of the BESS as an uninterruptible power supply (UPS). The algorithm detects the fault clearance using second-order differences of total harmonic distortion (THD) (SODT) of the current supplied by the BESS and allows the BESS to keep feeding to the healthy phase. A synchronism check is adopted between the utility and the BESS to minimize the transients at the moment of reclosing. To verify the proposed algorithm, the whole system and algorithm were modeled using ATP-EMTP. Various simulations are performed by varying the fault clearance time, fault types, fault resistances, and fault locations. The simulation results show that the BESS can be operated as a UPS and provide an improved reclosing scheme.

1. Introduction

The electric power industry is currently experiencing historical and significant restructuring of its conventional vertically integrated configuration. Specifically, the battery energy storage system (BESS) has been widely applied in power distribution systems as well as in renewable energy sources to ensure uninterruptible power supply. As BESSs are increasingly adopted in power distribution networks, utilities will have to adapt or change their practices and procedures. Accordingly, research has increasingly become focused on the grid connection of the BESS. These studies have focused on the power quality, operation, control strategy of the BESS, integration with renewable energy, and energy management [1–14]. However, only a small number of protection studies in power systems with BESSs have been performed. Among the protection issues, this study focuses on reclosing considering BESSs.

The recloser is a circuit-interrupting device for distribution systems in which the magnitudes of the fault currents are limited. The operation sequence of a recloser in the distribution system of the Korea Electric Power Corporation (KEPCO) has the fixed dead times of 0.5 s and 15 s. Distinguishing permanent faults from temporary faults in reclosing sequences is very important. However, conventional reclosing adopts a fixed dead time, irrespective of whether a fault is temporary or permanent in nature [15]. This leads to have dead time despite fault clearance before reclosing, which is a disadvantage of conventional reclosing. In transmission systems, various schemes have been proposed to detect fault clearance and reduce dead time [16–20]. However, these methods cannot be applied to distribution systems and only a small number of studies have examined the fault clearance in distribution systems [21].

The operation of the BESS under fault conditions depends on the purpose of its use, and hence, its effects on the reclosing are also different. The BESS can be used for frequency regulation and peak load shaving. The distribution system must be operated at a steady state without faults to use the BESS for frequency regulation and peak load shaving. The new challenges and countermeasures in reclosing of distribution systems with BESS used for those purposes were discussed in Ref. [22]. However, Ref. [22] does not consider the BESS when it is used as an uninterruptible power supply (UPS).

If the BESS is connected under fault conditions and supplies power to a healthy phase, the outage time will be significantly reduced, and thus it will improve the reliability of the power supply. In this case, however, the distribution system experiences a new challenge in reclosing because the BESS will not be disconnected from the distribution system even under fault conditions and will maintain the power supply to a healthy phase. Conventional reclosing schemes do not consider a synchronism problem between the utility and the BESS when reclosing is attempted. Due to the existence of both sources at the sending and receiving ends, a reclosing in distribution systems with BESS is very similar

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to reclosing in a transmission line, and thus the synchronism problem including voltage, phase angle, and frequency must be considered.

This study proposes a novel adaptive reclosing technique in distribution systems with the BESS as a UPS. Section 2 discusses the transient phenomena of BESS at fault conditions. Section 3 presents the proposed reclosing technique that considers the BESS. The proposed technique includes a method of fault clearance detection using total harmonic distortion (THD) of current from the BESS at fault conditions to provide the adaptive dead time. Section 4 describes the various simulations performed using the ATP-EMTP and ATP-EMTP/MODELS to verify the proposed reclosing technique. Finally, conclusions derived from our work are discussed in Section 5.

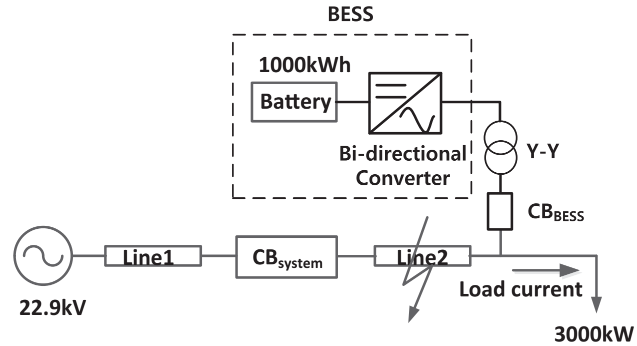

Fig. 1. System model to analyse the fault current contribution from BESS.

2. Transient phenomena of BESS at fault conditions

2.1. Fault current contribution from BESS

To discuss the applicability of BESS as UPS, this study first analyses the characteristics of the current supplied by BESS to both the healthy phase and faulted phase after tripping of the system current when the fault occurs.

The BESS is interconnected with the distribution system through power electronics. Inverters do not dynamically behave the same as synchronous or induction machines do. Inverters do not have a rotating mass component; therefore, they do not have inertia to contribute to the increase of fault current [23]. The fault current contribution during discharging of a BESS is very similar to that from inverter-based distribution generation (DG). Although there are no references that discuss fault current contribution from BESS, there are a number of studies that include some discussion on fault currents from inverter-based DG. Several relevant research documents about fault current contribution contain a “rule of thumb” of one to two times an inverter’s full load current for one cycle or less [23]. In Ref. [24], the fault current is considered to be about 10% above the converter rated current (i.e. 1.1 p.u.). In Ref. [25], the fault current is raised to about 1.5 p.u. from its full load current. The inverter-based distributed generation could produce 1.2 p.u. peak current for a period of approximately seven cycles [26]. These values are relatively small compared with that at system conditions with synchronous or induction machines. In other words, the fault current contribution supplied from the inverter based distributed generation mainly depends on the inverter design and control [27].

Therefore, this study considers that the fault current contribution from the BESS is less than 1.2 p.u. of the inverter’s full load current. Because power electronics are used, the fault current contribution from the BESS is limited to marginally more than the rated current, and hence the overcurrent relay will not operate to block the fault current injection from the BESS and the inverter will not shut down. In other words, the injection of low fault current by the BESS does not affect the distribution system.

2.2. Simulations

We simulated the fault current contribution from the BESS. Fig. 1 shows the distribution system model to analyse the characteristics of the current supplied by the BESS to the healthy phase and faulted phase. Line 1 and 2 are both 10 km long, and are ACSR (Aluminium Conductor Steel Reinforced) wire type of 95 mm^2. The capacities of the BESS and the load are 1000 kW h and 3000 kW, respectively.

The fault current contribution from the BESS is not influenced by the capacity of the BESS. The fault current contribution is determined by the inverter control as discussed in Section 2.1. The larger the capacity of the BESS, the longer it is able to maintain the power supply to the healthy phase. As shown in Fig. 1, the BESS is assumed to have a large enough capacity such that it does not completely discharge during its operation as UPS under fault conditions. All of the loads are single phase loads. The block diagram of the BESS model is presented in Fig. 1. The BESS is composed of a battery and a bidirectional converter. The BESS supplies power via a Y-Y transformer to the distribution system. If a transformer with Δ winding is used, the voltage swell with maximum 1.73 p.u. can occur on the healthy phase, and hence the BESS cannot supply steady state current to the healthy phase. A Li-ion battery is adopted because it is sufficient for improving power system reliability and power quality. The bidirectional AC-DC converter works as the interface between the battery and the AC grid. AC-DC converters with Pulse Width Modulation (PWM) are employed to increase power factor and to reduce current harmonics. Current control is widely used in the grid-tie bidirectional AC-DC converter applications because the grid side voltage is controlled by the AC grid. Among several current control technologies, PI control is applied as it is the most widely used control method for AC-DC converters [28,29]. The BESS and the distribution system are modeled by using ATP-EMTP [30].

The various fault conditions according to the fault types, fault resistances, and fault locations are simulated. The simulated fault types are single line-to-ground (SLG) faults (three cases), double line-to-ground (DLG) faults (two cases), and three phase faults (one case). The fault resistances of 0.1, 1, 10, and 100 Ω are considered to simulate from solid fault to high-impedance fault. In

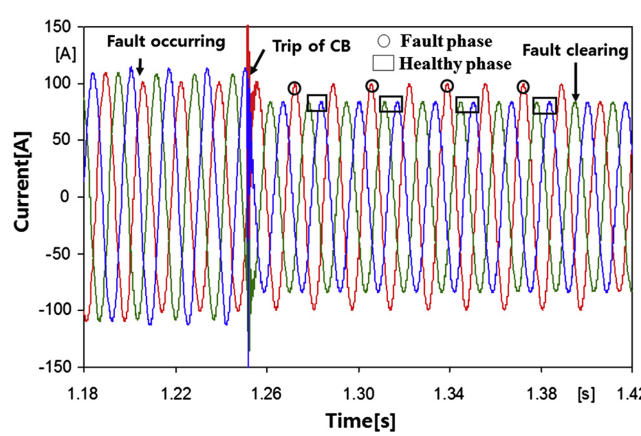

Fig. 2. Current supplied by BESS after tripping and before reclosing when SLG fault with fault resistance of 0.1 Ω and fault location of 50% has occurred.