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(54) **THERMAL ENERGY STORAGE APPARATUS, CONTROLLERS AND THERMAL ENERGY STORAGE CONTROL METHODS**

(75) Inventor: **Donald J. Hammerstrom**, West Richland, WA (US)

(73) Assignee: **Battelle Memorial Institute**, Richland, WA (US)

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H02J 3/28 (2006.01)
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(52) **U.S. Cl.**
CPC ***H02J 3/28*** (2013.01); ***H05B 1/0227*** (2013.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,956,462	A *	9/1999	Langford	392/449
5,968,393	A	10/1999	Demaline	
6,363,216	B1 *	3/2002	Bradenbaugh	392/463
2007/0132249	A1 *	6/2007	Andrew et al.	290/52
2007/0162689	A1	7/2007	Choi	
2007/0220907	A1	9/2007	Ehlers	
2007/0290507	A1	12/2007	Andrew et al.	
2009/0164393	A1 *	6/2009	Takano et al.	705/412
2010/0072817	A1 *	3/2010	Hirst	307/31

(Continued)

FOREIGN PATENT DOCUMENTS

EP	2101051	9/2009
JP	2006-029635	2/2006

(Continued)

OTHER PUBLICATIONS

Lu et al., "Design Consideration for Frequency REsponsive Grid Friendly Appliances" IEEE 2005 Power Engineering Society TD 2005/2006; pp. 647-652; May 21-24, 2006.*

(Continued)

Primary Examiner — Marc Norman
(74) *Attorney, Agent, or Firm* — Wells St. John P.S.

(57) **ABSTRACT**

Thermal energy storage apparatus, controllers and thermal energy storage control methods are described. According to one aspect, a thermal energy storage apparatus controller includes processing circuitry configured to access first information which is indicative of surpluses and deficiencies of electrical energy upon an electrical power system at a plurality of moments in time, access second information which is indicative of temperature of a thermal energy storage medium at a plurality of moments in time, and use the first and second information to control an amount of electrical energy which is utilized by a heating element to heat the thermal energy storage medium at a plurality of moments in time.

24 Claims, 8 Drawing Sheets