

A novel approach for real-time implementation of MVDC shipboard power system reconfiguration

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ABSTRACT

In a Shipboard Power System (SPS), faulty components are separated from the rest of the system after the occurrence of faults. In this situation, it is important to quickly restore the power supply to the affected parts of the SPS and reconfigure the system to improve its reliability and ensure safe and satisfactory operation of the system. Similar to terrestrial power systems, onboard post-fault reconfiguration aims to ensure the maximum delivery power/service to the system's loads following a fault. In this paper, in order to deal with the reconfiguration problem during the fault situations in Medium Voltage DC (MVDC) SPS, a real-time Simulated Annealing (SA)-based reconfiguration technique is designed and implemented in the Real-Time Digital Simulator (RTDS). To validate the proposed approach, two MVDC SPS models including four and six zonal loads are used to simulate several fault scenarios. The simulation results demonstrate the effectiveness of the proposed approach to reconfigure the system under different fault situations in the real-time operation of the SPS.

1. Introduction

The Shipboard Power System (SPS) plays a major role in the next-generation Navy fleets. With the increasing power demand from propulsion loads, ship service loads, weaponry systems and mission systems, a stable and reliable SPS is critical to support different aspects of ship operation. It also becomes the technology-enabler to improve ship economy, efficiency, reliability, and survivability [1]. An appropriate system reconfiguration action becomes fundamental for the design and analysis of SPS. The primary objectives of the system reconfiguration are to minimize the effects of the fault to enable reliable, safe, and robust restoration, and maintain the system performance close to normal conditions. Similar to terrestrial power systems, onboard post-fault reconfiguration aims to ensure the maximum delivery power/service to the system's loads following a fault [2].

Several papers in the literature have dealt with the reconfiguration problem in the power systems [3–11]. The reconfiguration objectives considered in these works include power loss reduction [7], preserving of the stability margins [8], minimization of the number of switch operations [10], and maximizing the number of the served loads [11]. However, in SPS, due to the underlying tightly-coupled distribution network, the active power loss is considered negligible compared to the other types of power systems, and it is not considered as a critical

objective for SPS reconfiguration problem [9]. Another unique feature of SPS is that the priorities of the loads in different missions are different; thus, this fact also needs to be taken into account during the reconfiguration process. These features have motivated researchers to investigate reconfiguration methodologies exclusively for the SPS.

Currently-used techniques to solve the SPS reconfiguration problem include: meta-heuristic search techniques [8], graph theory [12], network flow approach [13], and expert system [14]. As a meta-heuristic optimization approach, Genetic Algorithm (GA) is widely adopted in literature, where the binary GA's variables are integrated into the problem formulation to search the optimal network configuration [15,16]. In [17], authors have proposed a combined GA and graph theory algorithm to solve the reconfiguration problem for real-time analysis of the SPS. Particle Swarm Optimization (PSO) with Ant Colony Optimization (ACO) is used in [18] to find the optimal topology of the SPS's network while meeting the security constraints. However, as the number of feasible solutions increases during the reconfiguration process, the size of the optimization problem becomes critical, and convergence may be affected. Therefore, existing approaches may not be applicable for real-time operation of the SPS.

Real-time power system simulations can be done through Real Time Digital Simulator (RTDS) and its Graphical User Interface (GUI)-based design platform (RSCAD). A reconfiguration problem is essentially an

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Nomenclature		GAMS	General Algebraic Modeling System
Acronyms		Variables	
SPS	Shipboard Power System	N	number of the loads
MVDC	Medium Voltage Direct Current	M	number of the generating units
SA	Simulated Annealing	W_i	priority level associated with ith load
RTDS	Real-Time Digital Simulator	P_i	power consumption for the ith load,
GA	Genetic Algorithm	X_i	breaker status corresponding to the ith load
PSO	Particle Swarm Optimization	X_{Gi}	breaker status corresponding to the ith generator
ACO	Ant Colony Optimization	a, b	weighting factors that are adjusted to reflect the Relative importance of each objective function
GUI	Graphical User Interface-based	$Z(T)$	normalization function
MVAC	Medium Voltage AC	K_b	Boltzmann constant
DSP	Digital Signal Processor	E	current state of the system energy
RTAC	Real-Time Automation Controller	E_0	new state of the system energy
GPC	Giga Processor Card	T	temperature
TPC	Triple Processor Card		
UML	Unified Modeling Language		

optimization problem in which commercial simulation programs such as MATLAB and RTDS-MATLAB interface platforms are used to simulate and implement the problem [9,17]. In [9], an intelligent reconfiguration strategy for a Medium Voltage AC (MVAC) is implemented in the RTDS, where the reconfiguration algorithm is executed on the Digital Signal Processor (DSP). A Real-Time Automation Controller (RTAC) is used in [17] to perform the reconfiguration. However, those approaches require intensive computation overhead and need extensive simulations due to the complexity of SPS models. Therefore, there would be an inconsistency between the time required for actual hardware operation and that for software computation [19,20].

Another issue regarding the real-time implementation of the SPS reconfiguration problem is the communication delay between the RTDS and other optimization platforms. A communication delay occurs during the synchronization and information exchange between the optimization tool (MATLAB, DSP, etc.) and the RTDS. This information include the power network's states from the RTDS and the computed control outputs from the optimization tool. One approach to deal with this issue is to utilize the script environment inside the Runtime environment of RSCAD software in the RTDS to reduce the communication delays. With the proposed approach, the implementation of the optimization technique happens inside the RTDS, and it will remove the extra communication between RTDS and other computational platforms such as MATLAB. To the best knowledge of the authors, there

have been no systematic approach to address the MVDC SPS reconfiguration problem, particularly with a full RTDS implementation. This study aims to implement an intelligent real-time reconfiguration algorithm in the RTDS platform through an optimization technique implemented inside the RTDS.

Generally, the use of the RTDS scripting environment is sometimes computationally infeasible due to the limited functionality of the RTDS scripting language. In this paper, Simulated Annealing (SA) optimization method, which enjoys some advantages over other meta-heuristic methods, is employed to solve the reconfiguration problem in RTDS. The main advantage of SA optimization technique is its simplicity, even for complex problems. In addition, this algorithm is not a population-based algorithm, which makes the algorithm less computationally expensive.

The main contributions of this paper are summarized as follows.

- With respect to the previous research works on the topic, such as [9,17,21], this paper is presenting a novel approach to implement the real-time intelligent reconfiguration of the SPS. In this paper, the detailed modeling of the MVDC SPS has been performed with RTDS, which is the closest representation of the real SPS. With the proposed approach, the extra communication between RTDS and other optimization platforms such as MATLAB will be removed, and the RTDS scripting environment is utilized to solve the reconfiguration

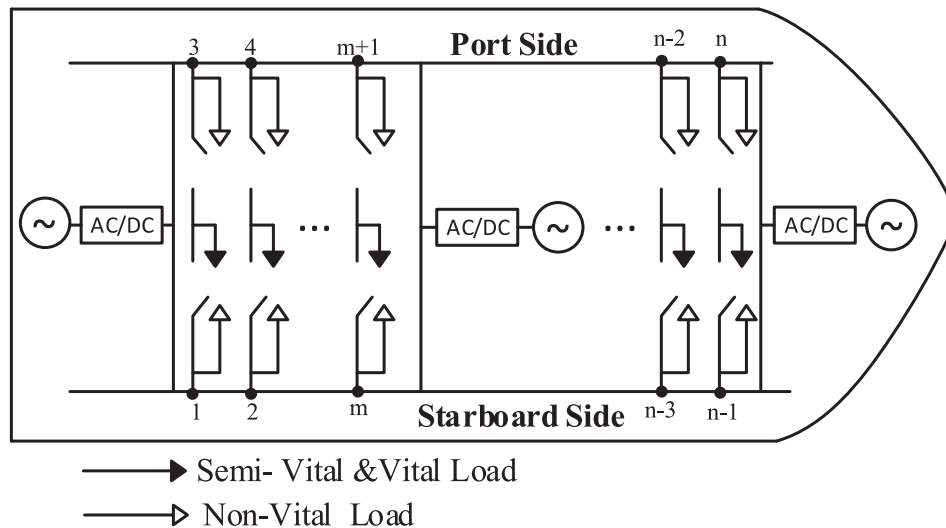


Fig. 1. Zonal MVDC shipboard power system model.

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