This paper deals with the development of a new electromagnetic transient (EMT)-transient stability (TS) hybrid simulation platform and its application to a detailed fault-induced delayed voltage recovery (FIDVR) study on the WECC system. A new EMT-TS hybrid simulation platform, which integrates PSCAD/EMTDC and the open source power system simulation software InterPSS has been developed. A combined interaction protocol with an automatic protocol switching control scheme is proposed. A multi-port three-phase Thévenin equivalent is developed for representing an external network in an EMT simulator. Correspondingly, the external network is represented in three-sequence, and a three-sequence TS simulation algorithm is developed. These techniques allow simulation of unsymmetrical faults within the internal network without the constraint of phase balance at the boundary. The effectiveness of the proposed techniques is first tested on the IEEE 9-bus system. Subsequently, the proposed hybrid simulation approach is applied to a detailed FIDVR study on a large WECC system. The study shows that a normally cleared single-line-to-ground (SLG) fault in the transmission system could lead to an FIDVR event, with compressor motors of the air conditioning units on the faulted phases stalling first, followed by a propagation of motor stalling to the unfaulted phase. Moreover, similar events are observed in simulations with a wide range of load compositions. Lastly, the effect of the point-on-wave (POW) at which a fault is applied on the occurrence of an FIVDR event is also analyzed.