INTISARI

Stabilitas frekuensi merupakan aspek penting dalam operasional *microgrid*, terutama pada sistem tegangan menengah yang memadukan berbagai teknologi *distributed generation* (DG). Penelitian ini menganalisis kinerja stabilitas frekuensi tiga teknologi DG, yaitu diesel genset, konverter dengan *droop control*, dan konverter dengan *virtual synchronous machine* (VSM), baik pada konfigurasi nonhibrida maupun hibrida. Evaluasi dilakukan menggunakan lima metrik, yaitu frekuensi nadir, *rate of change of frequency* (RoCoF), *overshoot frequency*, *settling time*, dan *steady-state frequency deviation*.

Pemodelan dilakukan pada *MV Microgrid Application Example* dari CIGRE menggunakan DIgSILENT PowerFactory. Simulasi mencakup tiga mode operasi, yaitu *interconnected*, *islanded*, dan *transition*. Simulasi juga dilakukan pada empat jenis gangguan untuk menilai respons frekuensi. Pada konfigurasi nonhibrida, setiap teknologi DG menunjukkan karakteristik respons yang berbeda terhadap gangguan. Konverter *droop* dan VSM menghasilkan nilai RoCoF awal yang lebih kecil dan respons yang cepat, tetapi keduanya lebih sensitif terhadap gangguan mendadak terutama pada mode *islanded* karena tidak didukung oleh inersia mekanis. Sebaliknya, diesel genset memberikan inersia alami yang besar namun menunjukkan respons awal yang lambat akibat keterbatasan mekanis *governor* dan sistem turbin.

Pada konfigurasi hibrida, ketiga teknologi DG bekerja secara sinergis. Konverter *droop* memberikan respons daya aktif yang cepat segera setelah gangguan, konverter VSM menyediakan redaman sekaligus inersia virtual untuk menahan perubahan frekuensi, dan diesel genset memberikan stabilitas daya mekanis. Kombinasi karakteristik ini menghasilkan respons frekuensi yang lebih seimbang dan pemulihan yang lebih terkendali pada sebagian besar skenario sehingga kinerja sistem tetap stabil meskipun terjadi variasi jenis gangguan. Kombinasi antara diesel genset sebagai sumber inersia mekanis dan konverter *droop* maupun konverter VSM sebagai unit statis juga mampu menjaga stabilitas frekuensi dan pembagian daya tanpa memerlukan kontrol terpusat baik pada mode *interconnected* maupun *islanded*.

Kata kunci : stabilitas frekuensi, *microgrid*, *droop control*, *virtual synchronous machine*, diesel genset.

ABSTRACT

Frequency stability is a critical aspect of microgrid operation, particularly in medium-voltage systems that integrate various distributed generation (DG) technologies. This study investigates the frequency stability performance of three DG technologies, namely diesel generators, droop-controlled converters, and virtual synchronous machine (VSM) converters, evaluated under both non-hybrid and hybrid configurations. The assessment is conducted using five key metrics: frequency nadir, rate of change of frequency (RoCoF), overshoot frequency, settling time, and steady-state frequency deviation.

The system model is based on the MV Microgrid Application Example from CIGRE and implemented using DIgSILENT PowerFactory. Simulations are carried out in three operating modes, namely interconnected, islanded, and transition, as well as four disturbance scenarios to evaluate the frequency response. In the non-hybrid configuration, each DG technology demonstrates different dynamic characteristics when subjected to disturbances. Droop-controlled and VSM converters produce smaller initial RoCoF values and faster responses, but they are more sensitive to sudden disturbances, particularly in islanded operation due to the absence of mechanical inertia. In contrast, diesel generators provide high natural inertia but exhibit slower initial responses caused by the mechanical limitations of the governor and turbine system.

In the hybrid configuration, the three DG technologies operate synergistically. The droop converter provides a fast active power response immediately after a disturbance, the VSM converter offers damping and virtual inertia to counteract frequency deviations, and the diesel generator contributes mechanical power stability. The combination of these characteristics results in a more balanced frequency response and a more controlled recovery in most scenarios, allowing the system to remain stable under different types of disturbances. The integration of diesel generators as mechanical inertia sources with droop and VSM converters as static units is also capable of maintaining frequency stability and power sharing without requiring centralized control in both interconnected and islanded modes.

Keywords : *frequency stability, microgrid, droop control, virtual synchronous machine, diesel generator*.