ABSTRACT

This research presents the design and performance evaluation of a sensorless position control system for a three-phase induction motor using Field Oriented Control (FOC) combined with a voltage-model flux estimator and cascade PID controllers. The induction motor is modeled in the dq reference frame and driven by a three-phase voltage source inverter. Rotor-flux-oriented FOC is implemented to decouple torque and flux, where the d-axis current generates rotor flux and the q-axis current produces electromagnetic torque. A flux estimator based on the stator voltage model in the αβ/dq frame is developed to reconstruct rotor flux and electrical rotor angle from measured stator voltages and currents, thereby eliminating the need for a mechanical position sensor.

The inner current loops and speed loop are controlled by PI controllers tuned in the frequency domain using selected crossover frequencies and phase margins, while the outer position loop uses a PD controller adjusted also through frequency domain. The complete system is implemented and tested via MATLAB/Simulink simulations under various position reference steps and load torque disturbances.

The no-load test results show that the system is capable of tracking each input value with small deviations. The rise time values at all setpoints meet the criteria of 10%–90% (≈0.3 s) so that the initial response is considered fast, while the overshoot is below the limit of <5% which indicates that the system damping is quite good and there is minimal oscillation. However, all settling time values have not met the criteria of ±1% = 0.5 s, which indicates that there are still small oscillations around the steady state before the response is completely stable. On the other hand, the steady-state error in the no-load test is around 0.01 rad, so the final accuracy of the system is considered good. In the loaded test (25 Nm and 50 Nm) with a change in the setpoint of 0 → 2 rad, the system performance decreases. The estimated angle value at steady state is at 1.96 rad with an error of 0.04 rad. In addition, the settling time of 0.6 s and overshoot of 6.5% do not meet the specified criteria, although the rise time remains at 0.2 s. Testing of gradual load variations of 10–50 Nm at a setpoint of 2 rad shows that the system remains stable and is able to return to the reference with a minimum drop of 1.95, so the load disturbance rejection capability is classified as good. Overall, the system successfully maintains stability and fast response, but improvements in control tuning and robust estimator are needed to minimize errors and accelerate settling under loaded conditions.

Kata kunci— *field oriented control, sensorless position control, induction motor, flux estimator, PID controller*

INTISARI

Penelitian ini menyajikan perancangan kinerja sistem kendali posisi tanpa sensor (*sensorless*) pada motor induksi tiga fasa dengan menerapkan metode *flux estimator* berbasis model tegangan) yang dikombinasikan dengan *Field Oriented Control* (FOC) serta pengendali PID berjenjang (*cascade*). Motor induksi dimodelkan dalam kerangka dq dan dikendalikan oleh inverter tegangan tiga fasa. Skema FOC dengan orientasi fluks rotor digunakan untuk mendekuple arus penghasil fluks (id) dan arus penghasil torsi (iq). Estimator fluks berbasis model tegangan pada frame αβ/dq dikembangkan untuk merekonstruksi fluks rotor dan sudut rotor elektrik dari pengukuran tegangan dan arus stator, sehingga tidak diperlukan sensor posisi mekanik.

Loop arus bagian dalam dan l*oop* kecepatan dikendalikan oleh pengendali PI yang dituning pada domain frekuensi melalui penentuan frekuensi crossover dan phase margin, sedangkan *loop* posisi bagian luar menggunakan pengendali PD yang disesuaikan dengan *frequency domain* Sistem lengkap diimplementasikan dan diuji melalui simulasi MATLAB/Simulink terhadap berbagai skenario perubahan referensi posisi dan variasi torsi beban.

Hasil pengujian tanpa beban menunjukkan bahwa sistem mampu melakukan *tracking* pada setiap nilai masukan dengan deviasi kecil. Nilai rise time pada seluruh setpoint memenuhi kriteria 10%–90% (≈0,3 s) sehingga respon awal dinilai cepat, sedangkan *overshoot* berada di bawah batas <5% yang mengindikasikan redaman sistem cukup baik dan minim osilasi. Meskipun demikian, seluruh nilai settling time belum memenuhi kriteria ±1% = 0,5 s, yang menunjukkan masih terdapat osilasi kecil di sekitar keadaan tunak sebelum respons benar-benar stabil. Di sisi lain, steady-state error pada pengujian tanpa beban berada di sekitar 0,01 rad, sehingga akurasi akhir sistem dinilai baik. Pada pengujian berbeban (25 Nm dan 50 Nm) dengan perubahan setpoint 0 → 2 rad, performa sistem menuru. Nilai sudut estimasi pada keadaan tunak berada pada 1,96 rad dengan *error* 0,04 rad. Selain itu, *settling time* sebesar 0,6 s dan *overshoot* 6,5% belum memenuhi kriteria yang ditetapkan, meskipun rise time tetap memenuhi yaitu sebesar 0,2 s. Pengujian variasi beban bertahap 10–50 Nm pada setpoint 2 rad menunjukkan sistem tetap stabil dan mampu kembali mendekati referensi dengan *drop* minimum 1,95, sehingga kemampuan *load disturbance rejection* tergolong baik. Secara keseluruhan, sistem berhasil mempertahankan kestabilan dan respons cepat, tetapi diperlukan peningkatan penalaan kontrol dan *robust estimator* untuk memperkecil *error* dan mempercepat settling pada kondisi berbeban.

Keywords— *field oriented control*, control posisi tanpa sensor, motor induksi, fluks estimator, kendali PID