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Eve: 378 FASE NACIONAL I

Folios: 84



Industria y Comercio

SUPERINTENDENCIA

DELEGATURA PROPIEDAD INDUSTRIAL

SOLICITUD
REGISTRO DE PATENTE DE INVENCION
PCT

EXPEDIENTE No _____

TITULO CONTROL DE TORQUE DEL MOTOR DE
INDUCCIÓN EN UN SISTEMA DE BOMBEO

CLASIFICACION INTERNACIONAL _____

SOLICITANTE UNICO, INC

DOMICILIO Wisconsin, Estados Unidos de América

APODERADO DARIO CARDENAS NAVAS

BOGOTA D.C. _____

PETITORIO



SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO



No. 11-133080- -00000-0000

Fecha: 2011-10-07 15:13:08 Dep. 2020 DIR.NUEVASCR
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FORMULARIO UNICO DE SOLICITUD DE PATENTE PCT ENTRADA EN FASE NACIONAL

①

SOLICITUD DE:



Patente de Invención



Patente de Modelo de Utilidad



Capítulo I



Capítulo II

②

SOLICITANTE

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IDENTIFICACION



NIT



NIT



Otro



Otro

Cuál
Número

③

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IDENTIFICACION



NIT



NIT



Otro



Otro

Cual
Número 17066629 BTA TP 1250

④

INVENTOR(ES)

Nombre: VER RELACION

Dirección: VER RELACION

Nacionalidad o Domicilio:

⑤

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Solicitud Internacional No. PCT/US2010/027494 Fecha 16.03.2010

Publicación Internacional No. WO 2010/107801 Fecha 23.09.2010

⑥

Título(54):

CONTROL DE TORQUE DEL MOTOR DE INDUCCIÓN EN UN SISTEMA
DE BOMBEO

⑦

Clasificación Internacional (51):

⑧

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(33)País de Origen

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15.03.2010

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12/724,120

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Comprobante de Pago No.:

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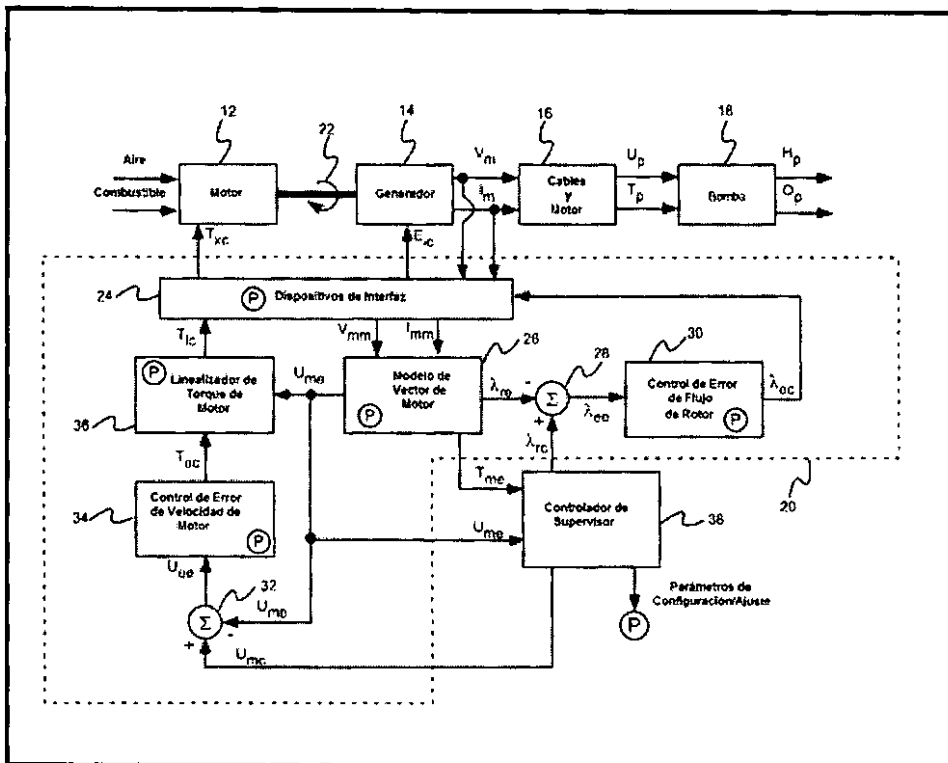
Fecha

27.09.2011

ANEXOS

- ☒ Comprobante de pago de la tasa de presentación de la solicitud.
- ☐ Documento que acredita la existencia y representación legal cuando el solicitante sea persona jurídica.
- ☐ Poderes, si fuere el caso.
- ☐ Documento de cesión del inventor al solicitante o a su causante.
- ☒ Traducción de la solicitud internacional al castellano (Resumen, Resumen, descripción, reivindicaciones, dibujos)
- ☐ Copia del examen preliminar internacional efectuado por la Autoridad Internacional de Examen Preliminar (IPEA)
- ☐ Traducción del examen preliminar internacional efectuado por la IPEA.
- ☐ De ser el caso, copia del contrato de acceso.
- ☐ De ser el caso, documento que acredite la licencia o autorización de uso de conocimientos tradicionales de las comunidades indígenas.
- ☐ De ser el caso, certificado de depósito del material biológico.
- ☒ Arte final 12x12.
- ☐ De ser el caso, información sobre otras solicitudes de patente o títulos obtenidos en el extranjero por el mismo titular o su causante, relacionadas parcial o totalmente con la invención de esta solicitud.
- ☒ Recibo por reivindicaciones adicionales No 11-0094723
- ☒ Prioridad
<http://www.wipo.int/patentscope/search/en/detail.jsf?sessionId=0A9BB5826B9848E97E9407521B3A4D81.wapp1?docId=WO2010107801&recNum=1&tab=PCTDocuments&maxRec=&office=&prevFilter=&sortOption=&queryString=>

11 FIGURA CARACTERISTICA



12

Solicito la Concesión de la patente

NOMBRE: **DARIO CARDENAS NAVAS**

FIRMA:

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(51) Clasificación Internacional :

(71) Solicitante(s) UNICO, INC

(72) Inventor(es) Thomas L Beck, Michael D. Dry, Mark E. Garlow , Michael O Lucas, Michael A. MacDonald, Ronald G. Peterson

(74) Apoderado: DARIO CARDENAS NAVAS

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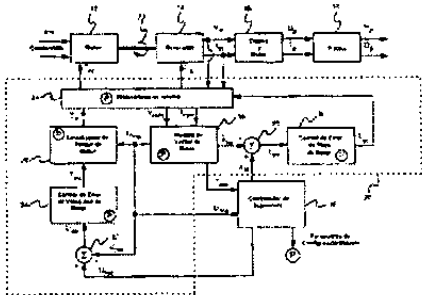
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(54) Titulo CONTROL DE TORQUE DEL MOTOR DE INDUCCIÓN EN UN SISTEMA DE BOMBEO

(21) N° de solicitud:		(22) Fecha de solicitud:	
(51) Clasificación Internacional :			
(71) Solicitante(s) UNICO, INC			
(72) Inventor(es) Thomas L Beck, Michael D. Dry, Mark E. Garlow , Michael O Lucas, Michael A. MacDonald, Ronald G. Peterson			
(74) Apoderado: DARIO CARDENAS NAVAS			
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No. de solicitud PCT/US2010/027494			



(54) Título: CONTROL DE TORQUE DEL MOTOR DE INDUCCIÓN EN UN SISTEMA DE BOMBEO

(57) Resumen:

Se proporciona un sistema y método para controlar la velocidad de un motor que impulsa una carga que se conecta eléctricamente a un generador impulsado por un motor, a través del uso de un primer bucle de regulación por reacción configurado para controlar el flujo de rotor del motor al controlar la excitación de campo del generador, y un segundo bucle de regulación por reacción configurado para controlar la velocidad del motor al controlar la posición del obturador del motor.

(21) N° de solicitud:					(51) Int Cl:
22) Fecha de solicitud:					(71) Solicitante(s) UNICO, INC
(30) Prioridad	(31) No. Prioridad	32) Fecha	(33) País	(72) Inventor(es) Thomas L Beck, Michael D. Dry Mark E. Garlow , Michael O Lucas Michael A. MacDonald, Ronald G. Peterson	
	61/160,498	16.03.2009	US		
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					(74) Apoderado: DARIO CARDENAS NAVAS
(54) Título: CONTROL DE TORQUE DEL MOTOR DE INDUCCIÓN EN UN SISTEMA DE BOMBEO					

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SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO
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Industria y Comercio SUPERINTENDENCIA	RECIBO DE CAJA	No. 11 - 0094716
		Bogotá D.C., Septiembre 27 de 2011 - 12:23:55

RECIBIDO DE : CARDENAS & CARDENAS ABOGADOS PI LTDA NI 830.083.491

*** Soporte del Pago ***					
TIPO PAGO	BANCO	CUENTA	No. PAGO	FECHA PAGO	VR PAGO
CONSIGNACION	BANCO DE BOGOTA	062754387	186851372	27/09/2011	22.584.000.00

*** Conceptos Pagados ***			
CANT. RENTISTICO	CONCEPTO	Vr. UNDITARIO	Vr. CONCEPTO
1 50005-01-01 SOLICITUDES	110 PTC SOLICITUD DE PATENTE DE INVENCIÓN	571.000.00	571.000.00
			\$571.000.00

SON: **QUINIENTOS SETENTA Y UN MIL PESOS MONEDA CORRIENTE***

Responsable: _____
Recibo de Caja Aplicado al Expediente No. _____

SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO
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AS 15
ABOGADOS

SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO
NIT : 800.176.089-2
- / -

 Industria y Comercio SUPERINTENDENCIA	RECIBO DE CAJA	No. 11 - 0094723
		Bogotá D.C., Septiembre 27 de 2011 - 12:23:55

RECIBIDO DE : CARDENAS & CARDENAS ABOGADOS PI LTDA NI 830.083.491

*** Soporte del Pago ***					
TIPO PAGO	BANCO	CUENTA	No. PAGO	FECHA PAGO	VR. PAGO
CONSIGNACION	BANCO DE BOGOTA	062754387	186851372	27/09/2011	22.584.000.00

*** Conceptos Pagados ***			
CANT. RENTISTICO	CONCEPTO	Vr. UNDITARIO	Vr. CONCEPTO
6 50005-01-01 SOLICITUDES	1607 REIVINDICACION UNITARIA ADICIONAL A LAS 10 INICIALES	27.000.00	162.000.00
			\$162.000.00
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SON: **CIENTO SESENTA Y DOS MIL PESOS MONEDA CORRIENTE***

Responsable. _____
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SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO

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ABOGADOS

CONTROL DE TORQUE DEL MOTOR DE INDUCCIÓN EN UN SISTEMA DE BOMBEO

CAMPO DE LA INVENCION

5 Esta invención se relaciona de manera general con el control del desempeño de un motor de inducción y, más particularmente, con métodos para controlar el desempeño de un motor de inducción utilizado en un sistema de bombeo.

ANTECEDENTES DE LA INVENCION

10 En la industria del gas y el petróleo, se utiliza en ocasiones un motor (por ejemplo un motor diesel, a gasolina, a gas natural, o propano) para energizar un generador de tres fases. El generador, a su vez, suministra potencia a un motor
15 de inducción de tres fases utilizado para impulsar un aparato de bombeo mecánico. Si se opera el motor de inducción en tal sistema a velocidades variables, la capacidad de bombeo del sistema se expande enormemente. Sin embargo, métodos anteriores proporcionaban velocidad de operación variable de
20 la bomba en tales sistemas de bombeo que no han sido completamente satisfactorios. En un método utilizado anteriormente para operar una bomba a una velocidad variable en un sistema de bombeo impulsado por motor, se suministra potencia de voltaje y frecuencia variable a un motor de tres
25 fases que impulsa la bomba. Normalmente, en un sistema que utiliza un generador como la fuente de potencia eléctrica, se interpone un impulso de velocidad variable electrónico (a.k.a., un variador de frecuencia o VFD) entre el generador y el motor de inducción para proporcionar frecuencias y
30 voltajes variables al motor. Existen muchas desventajas potenciales de utilizar una impulsión de velocidad variable, que incluye armónicos de voltaje generados sobre los cables del motor que pueden dañar al motor, los armónicos actuales generados en la entrada del VFD pueden ocasionar problemas
35 para el generador, la complejidad en el diseño VFD y/o la necesidad de un transformador de salida costoso cuando se

utilizan mayores voltajes (más frecuentemente cuando los cables del motor son muy largos).

Para eliminar la necesidad de un variador de velocidad, algunos métodos anteriores emplean un sistema de potencia de frecuencia variable que varía la velocidad y excitación de un generador de tres fases para producir un voltaje y frecuencia de salida deseados en un intento por alcanzar la operación deseada del motor de tres fases en la bomba. La patente Estadounidense No. 7,170,262, otorgada a Pettigrew describe un sistema variador de velocidad de este tipo, y describe la operación de tal sistema en comparación con los sistemas anteriores del tipo que utilizan un variador de velocidad como se describió aquí anteriormente.

Desafortunadamente, los sistemas de potencia de frecuencia variable, del tipo ejemplificado por Pettigrew, tienen desventajas significativas, por ejemplo, intentar simplemente controlar la salida del generador de tres fases puede no producir la operación deseada de la bomba. La velocidad de salida del motor de inducción que impulso la bomba variará con base en factores tales como la carga de la bomba. Cuando eso ocurre, el usuario de tal sistema de potencia de frecuencia variable no tendrá el control preciso de la velocidad de la bomba y puede encontrar una variedad de situaciones indeseables. Por ejemplo, la bomba puede operar a una menor velocidad que la esperada, lo que resulta en una producción menos que óptima o la bomba puede operar a una mayor velocidad de la deseada y experimentar un "secado de bomba" o una condición de "bomba apagada" que hace que la bomba funcione sin fluido para ampliarse y lubricarse o la bomba se apagará para permitir que el fluido recargue la carcasa, haciendo que se decante el sedimento en la bomba. Estas condiciones resultarán en el daño de la bomba, lo que resulta en una vida reducida.

La presente invención se dirige a superar las desventajas descritas aquí, y adicionalmente, a mejorar el estado de la técnica en la industria del gas y petróleo.

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BREVE RESUMEN DE LA INVENCION

En una realización, se proporciona un sistema y método para controlar la velocidad rotacional de un motor que impulsa una bomba. Al controlar la velocidad rotacional del motor en lugar de la frecuencia del generador, la operación de la bomba se hace más precisa y se controla en forma exacta.

Se proporciona un sistema para controlar la velocidad de un motor que impulsa una carga. El motor se conecta eléctricamente a un generador que es impulsado por un motor. El generador incluye un campo controlable. El sistema incluye un primer bucle de retroalimentación configurado para limitar la diferencia entre el flujo magnético en el rotor del motor y un nivel comandado de flujo magnético en donde el flujo magnético en el rotor se estima con base en la medición de las entradas eléctricas a los cables del motor. Se configura un segundo bucle de retroalimentación para limitar la diferencia entre la velocidad del rotor del motor y una velocidad comandada en donde la velocidad del motor se estima con base en una medición de las entradas eléctricas a los cables del motor.

Se proporciona un método para controlar la velocidad de un motor que impulsa una carga. El motor se conecta eléctricamente a un generador que es controlado por un motor. El generador incluye un campo controlable y el motor tiene un obturador. El método incluye realizar periódicamente las etapas de medición de voltaje y entrada de corriente a los cables del motor. Con base en las mediciones de voltaje en las entradas de corriente a los cables del motor, se genera una señal que representa un estimado de flujo del rotor del motor. El estimado del flujo del rotor del motor se compara con una señal de comando de flujo de rotor que se utiliza

para generar una señal que representa el error de flujo del rotor. El método incluye adicionalmente la generación de una señal de comando de excitación de flujo con base en la señal que representa el error de flujo de rotor con la señal de comando de excitación de flujo que controla la excitación del campo del generador. Se genera una señal que representa un estimado de la velocidad del motor con base en las mediciones del voltaje y las entradas de corriente al motor. Se utiliza una comparación de la señal de comando de velocidad con la señal que representa un estimado de la velocidad del motor para generar una señal que representa el error de velocidad de motor. Se genera una señal de comando de posición de obturador con base en la señal que representa el error de velocidad de motor. Se genera una señal de comando de posición de obturador con base en la señal que representa el error de velocidad de motor con la señal de comando de posición de obturador que controla la posición del obturador del motor.

Se proporciona adicionalmente un sistema de control de bomba para controlar las entradas mecánicas a la bomba. La bomba se acopla a un motor eléctrico y el motor eléctrico se acopla a un generador controlado por un motor. El sistema de control de bomba incluye una unidad de control de error que tiene una pluralidad de dispositivos de interfaz. Un modelo de vector del motor se acopla a por lo menos dos de los dispositivos de interfaz. Un dispositivo de suma de flujo de rotor se configura para proporcionar un estimado de error de flujo acoplado al modelo de vector del motor y uno de los dispositivos de interfaz. Un dispositivo de suma de velocidad de motor se acopla al modelo de vector del motor y un control de error de velocidad de motor se acopla al dispositivo de suma de velocidad de motor y uno de los dispositivos de interfaz. El sistema de control de bomba incluye adicionalmente un controlador supervisor acoplado al dispositivo de suma de velocidad de motor, el modelo de vector del motor, y el dispositivo de suma de flujo de rotor,

en donde la velocidad del motor acoplado a la bomba se controla mediante un primer bucle de retroalimentación configurado para proporcionar un comando de corriente de excitación al generador y un segundo bucle de retroalimentación configurado para proporcionar un comando de posición de obturador para el motor. En otra realización, el sistema de control de bomba incluye un linealizador de torque del motor que se configura un linealizar un comando de torque del motor. El linealizador se acopla a por lo menos uno de los dispositivos de interfaz, al control de velocidad del motor y al modelo de vector del motor, en donde la ganancia del sistema de la posición del obturador es casi constante. Durante el arranque del sistema, se configura el control supervisor para fijarse a un nivel de flujo magnético para reducir la carga sobre el motor. En una realización, el controlador supervisor fija el flujo magnético a cero durante el arranque del sistema.

Otras realizaciones de la invención serán más evidentes a partir de la siguiente descripción detallada cuando se toman en conjunto con los dibujos acompañantes.

BREVE DESCRIPCIÓN DE LOS DIBUJOS

Los dibujos acompañantes se incorporan y forman parte de los diversos aspectos ilustrativos de la descripción de la presente invención y, junto con la descripción, sirven para explicar los principios de la invención. En los dibujos:

La FIGURA 1 es una realización de ejemplo de un sistema de control de motor de inducción que tiene una unidad de control de error de acuerdo con las enseñanzas de la presente invención:

La FIGURA 2 es un diagrama de bloques de una simulación de software Simulink realizado sobre un sistema similar al sistema de la figura 1; y

La FIGURA 3A-3D son descripciones gráficas de los resultados de la simulación realizada en el sistema de la figura 2.

Aunque la invención se describirá en relación con ciertas realizaciones preferidas, no hay un intento por limitarla a aquellas realizaciones. Por el contrario, se intenta que cubra todas las alternativas, modificaciones y equivalentes como se incluye dentro del espíritu y alcance de la invención según se define por las reivindicaciones adjuntas.

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DESCRIPCIÓN DETALLADA DE LA INVENCION

Ahora con referencia a la figura 1, se ilustra un sistema de control de bomba 10. Como se explicará más completamente adelante, el sistema de control de error 20 del sistema de control de bomba 10 monitorea una o más características de la entrada eléctrica a los cables y al motor 16 y, basado en lo que se observa, calcula las entradas mecánicas a la bomba 18 y ajusta la operación del motor 12 y el generador 14. Al controlar las entradas mecánicas a la bomba 18, la operación de la bomba es más precisa, exacta y depende de lo que se proporcionaría por un sistema que solo controla las salidas eléctricas de un generador.

En la entrada 12 del motor ingresa aire y combustible y, al quemar la mezcla de los mismos, genera una salida de motor mecánica rotatoria 22. La salida del motor mecánica rotatoria 22 depende de la posición T_{xc} , el combustible utilizado, la densidad y la temperatura del aire, etc. El motor 16 puede operar utilizando combustible diesel, gasolina, propanol líquido, gas natural u otros tipos de combustibles. El motor 12 se acopla en forma operativa a, e impulsa, al generador 14. A este respecto, la salida de motor mecánica giratoria 22 se acopla normalmente en forma directa a la entrada del mecanismo de generador 14. Aún así, otros tipos de conexiones tal como las cajas de engranajes, correas, acoplamientos de potencia hidráulica y similares se pueden emplear dependiendo de la aplicación particular. El generador 14 es un generador

de tres fases sincrónico, que tiene un campo que se puede controlar.

El generador 14 se acopla eléctricamente mediante cables eléctricos a un motor, que se representa colectivamente en 16. En el sistema mostrado, la bomba es una bomba centrífuga del tipo conocido como una bomba eléctrica sumergible (ESP), así tanto el motor 16 como la bomba 18 están dispuestos dentro de una carcasa por debajo del nivel terrestre y los cables 16 son de una longitud considerable. En un pozo de petróleo típico, por ejemplo, los cables 16 pueden tener miles de pies de largo. A través de los cables 16, el generador 14 suministra al motor 16 potencia eléctrica. En la realización ilustrada de la figura 1, el motor 16 es un motor de inducción de tres fases. Las entradas eléctricas del motor 16 se pueden caracterizar por los voltajes (V_m) y las corrientes (I_m). El motor 16 genera una salida mecánica rotatoria que se puede caracterizar mediante la velocidad de bomba (U_p) y el torque de bomba (T_p).

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El motor 16 se acopla mecánicamente a, e impulsa, la bomba 18, que se sitúa en o cerca a la parte inferior de la carcasa del pozo o se sumerge parcialmente en el fluido que se bombea (por ejemplo, petróleo y/o agua). La bomba 18 genera una salida de fluido que se puede caracterizar por, entre otros parámetros, la cabeza de bomba (H_p) y el flujo de bomba (Q_p).

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La unidad de control de error 20 está, en general, en comunicación eléctrica con el motor 12 y el generador 14. La unidad de control de error 20 también se configura para monitorear las entradas de voltaje (V_m) y las entradas de corriente (I_m) a los cables y al motor 16. La unidad de control de error 20 incluye dispositivos de interfaz 24, un modelo de vector del motor 26, un dispositivo de suma de flujo de motor 28, un control de error de flujo de rotor 30, un dispositivo de suma de velocidad de motor 32, y un control de error de velocidad de motor 34. La unidad de control de

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error 20 también puede incluir opcionalmente un linealizador de torque del motor 36. El dispositivo de interfaz 24 se emplea de manera general para manipular o convertir las señales y datos enviados o recibidos mediante la unidad de control de error 20. A este respecto, el dispositivo de interfaz 24 puede incluir numerosos componentes eléctricos tal como, por ejemplo, dispositivos de entrada/salida en paralelo, convertidos análogos a digital (A/D), convertidores digital a análogo (D/A), sensores de voltaje y corriente, estimadores de flujo, filtros, integradores y similares.

En la realización mostrada, los dispositivos de interfaz 24 tienen dos salidas. La primera salida es el comando de posición de obturador (T_{xc}), que se convierte desde el comando de error de torque (T_{ec}) del control de error de velocidad de motor 34 o, en sistemas en donde se utiliza el linealizador de torque del motor 36, la salida de comando de torque linealizado (T_{lc}) del linealizador de torque del motor 36. La segunda salida es el comando actual de excitación (E_{ic}) que se convierte desde el comando de error de flujo generado (λ_{ec}) por el control de error de flujo de rotor 30.

Para las entradas, los dispositivos de interfaz 24 generan tres señales de medición de voltaje de motor (V_{mm}) para representar los voltajes (V_m) en cada fase de los cables y motor 16 y dos señales de medición de corriente de motor (I_{mm}) para representa las corrientes (I_m) en dos de las tres fases. La corriente de la tercera fase se calcula fácilmente, debido a que las corrientes de las tres fases deben sumar cero, pero también se pueden medir.

El modelo de vector del motor 26 está en comunicación eléctrica con los dispositivos de interfaz 24, el dispositivo de suma de flujo de rotor 28, el controlador supervisor 38, el dispositivo de suma de velocidad de motor 32, y, cuando se emplea, el linealizador de torque del motor 36. El modelo de vector del motor 26 realiza diversas funciones matemáticas

utilizando las señales de medición de voltaje de motor (V_{mm}) y las señales de medición de corriente de motor (I_{mm}) con el fin de proporcionar estimaciones como se describe en la Patente Estadounidense No. 7,117,120 otorgada a Beck et al., (la Patente '120), que se incluye aquí como referencia. Por ejemplo, el modelo de vector del motor 26 calcula y genera los estimados del desempeño del motor de inducción 16 que incluye la velocidad de motor en el eje del motor (U_{me}), el flujo magnético del rotor (λ_{re}), y el torque mecánico del eje del motor (T_{me}).

El dispositivo de suma de flujo de rotor 28 descrito en la figura 1 recibe dos entradas, a saber el estimado de flujo de rotor (λ_{re}) del modelo de vector de rotor 26 y el comando de flujo de rotor (λ_{rc}) desde el controlador supervisor 38. Durante la operación regular, el comando de flujo de rotor (λ_{rd}) se mantiene de manera general en un valor constante para mantener el torque apropiado (T_p) del motor. Sin embargo, durante el arranque del motor 12, el comando de flujo de rotor (λ_{rc}) se puede reducir enormemente o aún mantener en cero para reducir la carga del motor 12. Basado en las entradas recibidas, el dispositivo de suma de flujo de rotor 25 genera una salida, a saber, el estimado de error de flujo (λ_{ee}).

El estimado de error de flujo (λ_{ee}) se recibe por parte del control de error de flujo de rotor 30. En general, el control de error de flujo de rotor 30 es una estructura de bucle de control diseñada para ajustar su salida para forzar el término de error a cero. En la realización de la figura 1, el control de error de flujo de rotor 30 es un controlador derivado integral proporcional (PID). Sin embargo, se pueden utilizar otros tipos de estructuras de control, tal como integral-proporcional (PI), controladores lógicos difusos, y similares, se pueden utilizar como se conocen en la técnica.

El control de error de flujo de rotor 30 extrae el comando de excitación de flujo (λ_{ec}) a los dispositivos de interfaz 24.

El dispositivo de suma de velocidad de motor 32 ilustrado en la figura 1 recibe dos entradas, a saber el estimado de velocidad de motor (U_{me}) del modelo de vector del motor 26 y el comando de velocidad de motor (U_{mc}) del controlador supervisor 38. Basado en las entradas recibidas, el dispositivo de suma de velocidad de motor 32 genera una salida, a saber el estimado de error de velocidad (U_{ee}).

El estimado de error de velocidad (U_{ee}) es recibido por el control de error de velocidad de motor 34. En general, el control de error de velocidad de motor 34 es una estructura de bucle de control diseñada para ajustar su salida para forzar el término de error a cero. En la realización ilustrada de la figura 1, el control de error de velocidad de motor 34 es un controlador derivado integral proporcional (PID). Sin embargo, los otros tipos de estructuras de control, tal como el integral-proporcional (PI), controladores lógicos de pulsos, y similares, se pueden utilizar como se conocen en la técnica. Como se muestra en la figura 1, el controlador de error de velocidad de motor 34 genera y envía el comando de torque del motor (T_{ec}) al linealizador de torque del motor opcional 36. Si el linealizador de torque del motor 36 es omitido desde la unidad de control de error 20, el comando de torque del motor (T_{ec}) se proporciona directamente a los dispositivos de interfaz 24.

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Cuando se utiliza, el linealizador de torque del motor 36 se utiliza para asegurar que se correlaciona una entrada particular con la acción correctiva deseada y apropiada. Por ejemplo, cuando se necesita un cambio de tres por ciento (3%) de cambio en el torque del motor, se puede requerir un cambio de obturador del diez por ciento (10%). En tales circunstancias, el linealizador de torque del motor 36

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manipula el comando de torque del motor (T_{ec}) recibido desde el controlador de error de velocidad de motor 34 de tal manera que se produce un comando de torque linealizado (T_{lc}). La linealización del comando de torque asegura que la ganancia de sistema del control de posición de obturador sea casi constante y, por lo tanto, más fácil de ajustar para una respuesta óptima. El comando de torque linealizado (T_{lc}) se genera a los dispositivos de interfaz 24 y se proporciona al motor 12. Como tal, se cambia la posición del obturador según se necesite para corresponder en forma correcta al comando de torque del motor (T_{ec}). Como se muestra en la figura 1, el linealizador de torque del motor 36 recibe dos entradas, a saber el comando de torque del motor (T_{ec}) desde el control de error de velocidad de motor 34 y el estimado de velocidad de motor (U_{me}) desde el modelo de vector del motor 26.

Con referencia aún a la figura 1, la mayor parte de los componentes de la unidad de control de error 20 están en comunicación eléctrica con el controlador supervisor 38. En particular, el control supervisor 38 suministra el comando de velocidad de motor (U_{mc}) al dispositivo de suma de velocidad de motor 32 y al comando de flujo de rotor (λ_{rc}) al dispositivo de suma de rotor de flujo 28. Los valores de estos dos comandos se pueden derivar mediante la entrada de operador manual, derivada de acuerdo con los métodos descritos en la patente '120, o derivada mediante otros medios automáticos. El controlador supervisor 38 recibe señales que representan estimados de la velocidad de motor en el eje del motor (U_{me}) en el torque mecánico del eje del motor (T_{me}). El controlador supervisor 38 también fija los parámetros de operación programables (designados por la letra "P" en un círculo) para los dispositivos de interfaz 24, en modelo de vector del motor 26, el control de error de flujo de rotor 30, el control de error de velocidad de motor 34 y, cuando se utiliza el linealizador de torque del motor 36. Los parámetros de operación programables incluyen ganancias, coeficientes de filtro, tabla de valores, parámetros de motor

y similares. El controlador supervisor 38 también puede recibir una variedad de otras entradas desde la unidad de control de error 20 y el sistema 10 y genera una variedad de otras salidas al sistema 10.

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En operación, el motor 12 dentro del sistema 10 se arranca aunque mantiene el comando de flujo de rotor (λ_{rc}) en o casi cero. Algún comando de flujo es de manera general necesario para producir suficiente voltaje para el motor (I_m) para el
 10 modelo de vector del motor 26 para que sea capaz de estimar la velocidad del motor (U_{me}). La velocidad del estator del motor 16 se determina mediante el módulo de vector del motor 26 utilizando señales de medición de voltaje de motor (V_{mm}) y (I_{mm}) que representa, respectivamente, los voltajes (V_m) y
 15 corrientes (I_m) de las fases de los cables y motor 16. Inicialmente, el controlador supervisor 38 también limita el valor calculado de la pendiente del motor 16 a cero (0) de tal manera que el estimado calculado de la velocidad del motor (U_{me}) es la misma que la velocidad rotacional eléctrica
 20 del estator del motor 16 y, por lo tanto, también proporcional a la velocidad rotacional del motor 12.

El modelo de vector del motor 26 proporciona el estimado de velocidad de motor (U_{me}) al controlador supervisor 38. Una vez
 25 el estimado de velocidad de motor (U_{me}) alcanza un nivel deseado o predeterminado, el controlador aumenta el comando de flujo de rotor (λ_{rc}) a un índice deseado. En la determinación del nivel predeterminado o deseado, el controlador 38 puede tener acceso y utilizar un parámetro
 30 fijo o una o más tablas de valores disponibles. Cuando se emplea una tabla de valores, el controlador supervisor 38 utiliza el estimado de velocidad de motor (U_{me}) para ubicar el comando de rotor de flujo apropiado y correspondiente (λ_{rc}) sobre la tabla de valores. En este momento, el controlador
 35 supervisor 38 también aumenta, en un índice controlado, el límite del valor calculado de la pendiente del motor 16 de

tal manera que el estimado calculado de la velocidad de motor (U_{me}) llega a ser la velocidad rotacional actual del motor 16 y la bomba 18.

- 5 El dispositivo de suma de flujo de rotor 28 compara el comando de rotor de flujo (λ_{rc}) con el estimado de rotor de flujo (λ_{re}) suministrado por el modelo de vector del motor 26. Basado en esta comparación, el dispositivo de suma de flujo de rotor 28 genera el estimado de error de flujo (λ_{ee}). El
- 10 estimado de error de flujo (λ_{ee}) se utiliza por el control de error de flujo de rotor 30 en donde se determina el comando de excitación de flujo (λ_{ec}). Luego el comando de excitación de flujo (λ_{ec}) pasa a través de los dispositivos de interfaz 24 y son recibidos por el generador 14 en la forma de comando
- 15 de corriente excitación (E_{ic}). El comando de corriente de excitación (E_{ic}) es recibido por y determina la corriente de campo del generador 14 y cambia los voltajes (D_m) y corrientes (I_m) de las fases de los cables y motor 16. El proceso descrito anteriormente repite a una frecuencia
- 20 determinada. Como tal, se opera un primer bucle de retroalimentación.

- En todo momento durante la operación, el dispositivo de suma de velocidad de motor 32 compara el comando de motor de
- 25 velocidad (U_{mc}) con el estimado de motor de velocidad (U_{me}) recibido desde el modelo de vector del motor 26 y genera el estimado de error de velocidad (U_{ee}).

- A continuación, el estimado de error de velocidad (U_{ee}) es
- 30 utilizado por el control de error de velocidad de motor 34 para generar el comando de torque del motor (T_{ec}). El comando de torque del motor (T_{ec}) se linealiza mediante linealizador de torque del motor 36 (cuando se utiliza la linealización para generar el comando linealizado del torque) (T_{lc}). El
- 35 comando linealizado de torque (T_{lc}) se transforma a través de los dispositivos de interfaz 24 y el comando de posición de

obturador (T_{xc}) se produce y suministra al motor 12. El proceso descrito anteriormente se repite a una frecuencia predeterminada. Como tal, se opera un segundo bucle de retroalimentación.

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El motor 16 impulsa la bomba 18 que opera con base en el comando de posición de obturador (T_{xc}) y el comando de corriente de excitación (E_{ic}). Por lo tanto, la velocidad de la bomba (U_p) y el flujo de bomba (Q_p) se manipulan en forma precisa o se mantienen constantes según se necesite para una aplicación particular mediante el uso de los primeros y segundos bucles de retroalimentación.

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Aquellos expertos en la técnica apreciarán que la invención supera así la desventaja experimentada en los métodos anteriores, tal como Pettigrew, que proporciona control de velocidad de bomba variable al remover o reducir sustancialmente la posibilidad de que el control de un generador no se traducirá en la operación deseada del motor y la bomba. De hecho, la realización de ejemplo del sistema 10 de la figura 1, de acuerdo con la invención, se basa en controlar el torque del motor en lugar de asumir la falla frecuente de la salida de frecuencia deseada del generador lo que resultará en la operación deseada del motor y la bomba como en sistemas anteriores.

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Como una ventaja agregada, la presente invención, a través de control preciso y el aumento de flujo de rotor, reduce el pico partiendo de la corriente retirada por el motor y, en forma correspondiente, la corriente que sea suministrada por el generador. En los sistemas anteriores en donde se opera un generador a una frecuencia y voltaje y luego se conmuta el motor en "a través de la línea", la corriente de motor aumentará a un valor tanto como un mil por ciento (1000 %) de la corriente de operación del motor. Para manejar tales corrientes de partida grandes, los sistemas anteriores utilizan este método que requiere muchos componentes en el

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sistema que son mucho mayores y más robustos de lo que ellos podrán haber necesitado. La presente invención reduce la corriente pico a menos de un ciento cincuenta por ciento (150 %) de la corriente de operación normal del motor, reduciendo sustancialmente por lo tanto el peso, la complejidad y el costo de los componentes requeridos para practicar la invención.

Con el fin de probar y evaluar el sistema 10 (o un casi equivalente del mismo), se realiza una simulación por computador utilizando el programa Simulink desarrollado por Math Works. La configuración y arquitectura de la simulación se describe esquemáticamente en el diagrama de bloques 40 de la figura 2.

El motor modelado en la simulación es un motor de cuatro cilindros de las partes de demostración Simulink. Adicionalmente, el control de error de velocidad de motor 34 y el control de error de flujo de rotor 30 son controladores integrales proporcionales (PI). La simulación produjo los resultados descritos en las figuras 3A a 3B. Como se puede ver en la figura 3B, la corriente máxima en el rotor generador y el estator del motor durante el arranque fue de aproximadamente 20 amperios, aunque las corrientes máximas constantes fueron aproximadamente de 14 amperios. En la figura 3C el flujo de rotor del motor (línea sólida) se ve que converge ligeramente sobre el comando de flujo de rotor (líneas discontinúas). Adicionalmente, en la figura 3D, la velocidad del motor (líneas sólidas) converge sobre y se mantiene en la velocidad comandada (líneas discontinúas).

Todas las referencias, que incluyen publicaciones, solicitudes de patente y patentes mencionadas aquí se incorporan por la presente como referencia al mismo grado como si cada referencia se hubiera indicado individual y específicamente para ser incorporada como referencia y se establece aquí en su totalidad.

Para propósitos de esta descripción, el término "acoplado" significa la unión de dos componentes (eléctricos o mecánicos) directa o indirectamente uno al otro. Tal unión
 5 puede ser de naturaleza móvil o estacionaria. Tal unión se puede lograr con dos componentes (eléctricos o mecánicos) y cualquier miembro intermedio adicional se forma integralmente como un único cuerpo individual con uno o los dos componentes y cualquier miembro adicional se une al otro. Tal unión puede
 10 ser de naturaleza permanente o alternativamente puede ser removible o liberable.

El uso de los términos "un" y "uno" y "el" y similares se refiere en este contexto de la descripción de la invención,
 15 especialmente en el contexto de las siguientes reivindicaciones se debe constituir que cubre el singular y el plural a menos que se indique otra cosa aquí o se contradiga claramente por el contexto. Los términos "que comprenden" "que tienen", "que incluyen", y "que contienen"
 20 se constituyen como términos abiertos (es decir, significa "que incluyen, pero no se limitan a") a menos que se indique otra cosa. La descripción de los rangos de los valores aquí está únicamente destinado a servir como un método abreviado de referencia individual a cada valor separado que cae dentro
 25 del rango, a menos que se indique de otra forma aquí, y cada valor separado se incorpore en la descripción como si fuera mencionado individualmente aquí. El término señal se constituye por incluir todos los medios de datos de comunicación y/o información que incluyen, pero no se limitan
 30 a estructuras de datos comunicadas entre módulos y sus rutinas en uno o más programas de computador, transmisión de datos en serie o paralelo y señales análogas. Todos los métodos descritos aquí se pueden realizar en cualquier orden adecuado a menos que se indique de otra forma aquí o se
 35 contradiga claramente por el contexto. El uso de cualquiera y todos los ejemplos, o lenguaje de ejemplo (por ejemplo, "tal como") suministrado aquí, se pretende que aclare únicamente

la invención y no posee una limitación del alcance de la invención a menos que se reivindique de otra forma. Ningún lenguaje en la descripción se debe constituir como indicador de cualquier elemento no reivindicado como esencial para la práctica de la invención.

Las realizaciones preferidas de esta invención se describen aquí, incluyendo la mejor forma conocida por los inventores para llevar a cabo la invención. Las variaciones de aquellas realizaciones preferidas pueden ser evidentes para aquellos medianamente versados en la técnica luego de la lectura de la anterior descripción. Los inventores esperan que los expertos empleen tales variaciones apropiadas, y los inventores pretenden que la invención no se practique de otra forma que la descrita específicamente aquí. De acuerdo con lo anterior, esta invención incluye las modificaciones y equivalentes de la materia objeto mencionada en las reivindicaciones adjuntas como lo permite la ley aplicable. Más aún, cualquier combinación de los elementos descritos anteriormente en todas las variaciones posibles de la misma está abarcada por la invención a menos que se indique aquí de otra forma o se contradiga de otra forma claramente por el contexto.

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REIVINDICACIONES

LO QUE SE REIVINDICA ES:

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1. Un sistema para controlar la velocidad de un motor que impulsa una carga, en donde el motor se conecta eléctricamente a un generador que es impulsado por un motor, dicho generador tiene un campo controlable, dicho sistema comprende:

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Un primer bucle de retroalimentación configurado para limitar la diferencia entre el flujo magnético en el rotor del motor y un nivel comandado de flujo magnético en donde el flujo magnético en el rotor se estima con base en la medición de las entradas eléctricas a los cables del motor; y

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Un segundo bucle de retroalimentación configurado para limitar la diferencia entre la velocidad del rotor del motor y una velocidad comandada en donde la velocidad del motor se estima con base en la medición de las entradas eléctricas a los cables del motor.

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2. El sistema de la reivindicación 1, en donde el motor suministra torque y el nivel del comando de flujo magnético se mantiene sustancialmente constante durante

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la operación regular del sistema, para mantener por lo tanto un torque sustancialmente constante desde el motor.

5 3. El sistema de la reivindicación 1, en donde el motor suministra torque y el nivel de comando de flujo magnético se reduce durante el arranque del sistema, reduciendo por lo tanto la carga sobre el motor.

10 4. El sistema de la reivindicación 3, en donde, el nivel de comando de flujo magnético se reduce sustancialmente a cero durante el arranque del sistema.

15 5. El sistema de la reivindicación 1, en donde el primer y segundo bucles de retroalimentación se configuran y conectan operativamente para:

Medir el voltaje y la entrada de corriente a los cables del motor;

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Generar una señal que representa un estimado del flujo del rotor del motor con base en las mediciones de voltaje y las entradas de corriente a los cables de motor;

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Comparar una señal de comando del rotor con la señal que representa un estimado de flujo del rotor del motor para generar una señal que representa el error de flujo del rotor;

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Generar una señal de comando de excitación de flujo con base en la señal que representa el error de flujo de rotor, la señal de comando de excitación de flujo controla la excitación del campo del generador;

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Generar una señal que representa un estimado de la velocidad del motor con base en las mediciones del voltaje y las entradas de corriente al motor;

5 Comparar una señal de comando de velocidad con la señal que representa un estimado de la velocidad del motor para generar una señal que representa el error de velocidad de motor; y

10 Generar una señal de comando de posición de obturador basado en la señal que representa el error de velocidad de motor, la señal de comando de posición de obturador controla la posición del obturador del motor.

15 6. El sistema de la reivindicación 5, comprende adicionalmente:

Generar un comando de torque del motor; y

Linealizar el comando de torque del motor,

20 En donde la ganancia del control de posición de obturador es casi constante y más fácil de ajustar para respuesta óptima.

25 7. Un método para controlar la velocidad de un motor que impulsa una carga, en donde el motor se conecta eléctricamente a un generador que es impulsado por un motor, dicho generador tiene un campo controlable y dicho motor tiene un obturador, que comprende realizar periódicamente las etapas de:

30 Medir las entradas de voltaje y corriente para los cables del motor;

35 Generar una señal que representa un estimado del flujo de rotor del motor con base en las mediciones de las entradas de corriente y voltaje para los cables de motor;

Comparar una señal de comando de rotor de flujo con la señal que representa un estimado del flujo de rotor del motor para generar una señal que representa el error de flujo de rotor;

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Generar una señal de comando de excitación de flujo con base en la señal que representa el error de flujo de rotor, la señal de comando de excitación de flujo que controla la excitación del campo del generador;

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Generar una señal que representa un estimado de la velocidad del motor con base en las mediciones de las entradas de voltaje y corriente al motor;

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Comparar una señal de comando de velocidad con la señal que presenta un estimado de la velocidad del motor para generar una señal que representa el error de velocidad de motor; y

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Generar una señal de comando de posición de obturador con base en la señal que representa el error de velocidad del motor, la señal de comando de posición de obturador que controla la posición del obturador del motor.

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8. El método de la reivindicación 7, en donde, el motor suministra torque y el método comprende adicionalmente, sostener la señal de comando de excitación de flujo sustancialmente constante durante la operación regular del sistema, manteniendo por lo tanto un torque sustancialmente constante desde el motor.

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9. El método de la reivindicación 7, en donde, el motor suministra torque y el método comprende adicionalmente, reducir la señal de comando de excitación de flujo

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durante el arranque del sistema, para reducir por lo tanto la carga sobre el motor.

10. El método de la reivindicación 9, que comprende
 5 adicionalmente, reducir la señal de comando de excitación de flujo durante el arranque del sistema a sustancialmente cero.
11. Un sistema de control de bomba para controlar las
 10 entradas mecánicas a una bomba, la bomba se acopla a un motor eléctrico, el motor eléctrico se acopla a un generador impulsado por un motor, el sistema de control de bomba comprende:

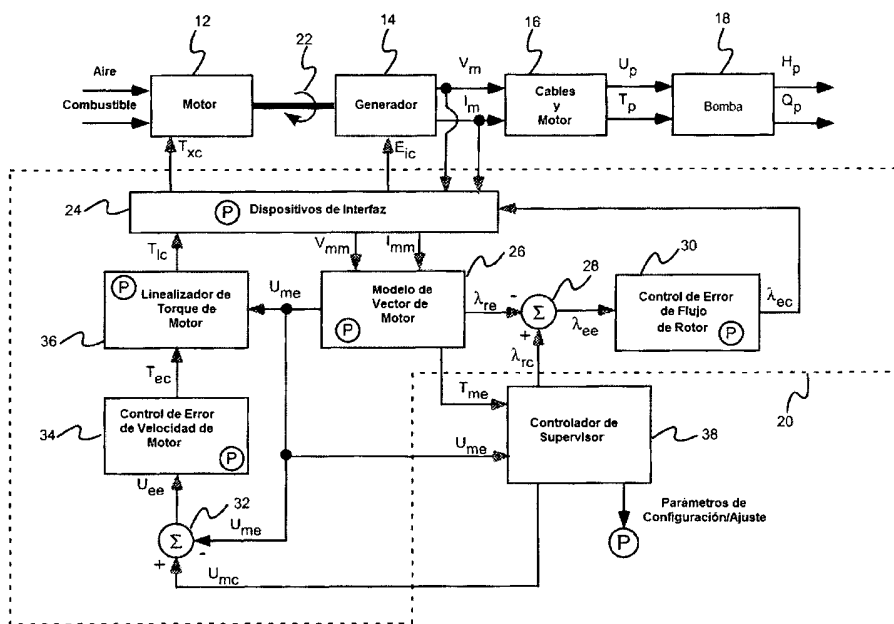
 - 15 Una unidad de control de error que incluye:
 Una pluralidad de dispositivos de interfaz;
 Un modelo de vector del motor acoplado a por lo menos dos de los dispositivos de interfaz;
 Un dispositivo de suma de flujo de rotor configurado
 20 para proporcionar un estimado de error de flujo acoplado al modelo de vector del motor y uno de los dispositivos de interfaz;
 Un dispositivo de suma de velocidad de motor acoplado al modelo de vector del motor; y
 - 25 Un control de error de velocidad de motor acoplado al dispositivo de suma de velocidad de motor y uno de los dispositivos de interfaz; y
 - 30 Un controlador supervisor acoplado al dispositivo de suma de velocidad de motor, el modelo de vector del motor, y el dispositivo de suma de flujo de rotor,

En donde la velocidad del motor acoplado a la bomba se controla mediante un primer bucle de retroalimentación configurado para proporcionar un comando de corriente de
 35 excitación al generador y un segundo bucle de retroalimentación configurado para proporcionar un comando de posición de obturador para el motor.

12. El sistema de control de bomba de la reivindicación 11, que comprende adicionalmente un linealizador de torque del motor configurado para linealizar un comando de torque del motor, el linealizador se acopla a por lo menos uno de los dispositivos de interfaz, el control de velocidad del motor y el modelo de vector del motor, en donde la ganancia del sistema del control de posición de obturador es casi constante.
13. El sistema de control de bomba de la reivindicación 11, en donde durante el arranque del sistema el controlador supervisor se configura para fijar un nivel de flujo magnético para reducir la carga sobre el motor.
14. El sistema de control de bomba de la reivindicación 13, en donde el flujo magnético se fija a cero durante el arranque del sistema.
15. El sistema de control de bomba de la reivindicación 11, que comprende adicionalmente el controlador supervisor configurado para programar parámetros de operación para los dispositivos de interfaz, el modelo de vector del motor, el control de error de flujo de rotor, y el control de error de velocidad de motor.
16. El sistema de control de bomba de la reivindicación 12, en donde el linealizador de torque del motor se configura para que se programe selectivamente por parte del controlador supervisor.

RESUMEN

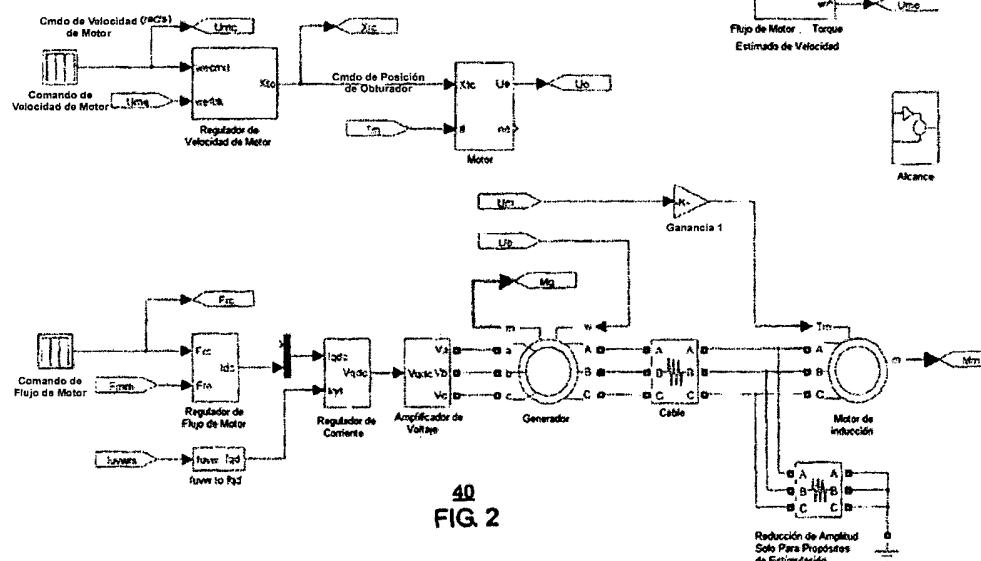
Se proporciona un sistema y método para controlar la velocidad de un motor que impulsa una carga que se conecta
5 eléctricamente a un generador impulsado por un motor, a través del uso de un primer bucle de retroalimentación configurado para controlar el flujo de rotor del motor al controlar la excitación de campo del generador, y un segundo bucle de retroalimentación configurado para controlar la
10 velocidad del motor al controlar la posición del obturador del motor.



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FIG. 1

Control VFG

Generador que impulsa el motor de inducción de carga variable. La referencia de flujo de motor se fija inicialmente en cero y el motor arranca a una velocidad inicial. Cuando el motor se instala, se aumenta la velocidad del motor y la referencia de flujo de motor hasta un punto fijo final.



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FIG. 2

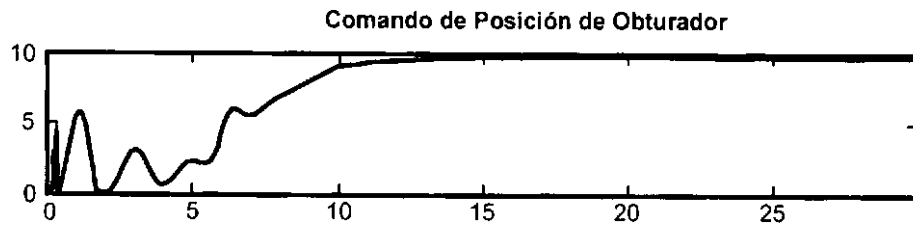


FIG. 3A

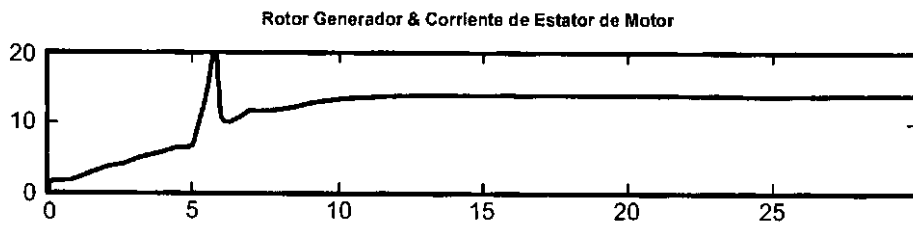


FIG. 3B

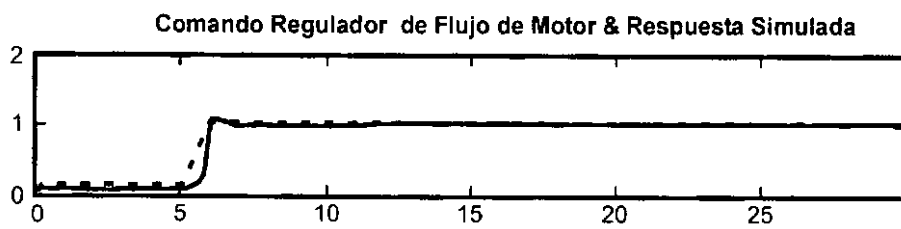


FIG. 3C

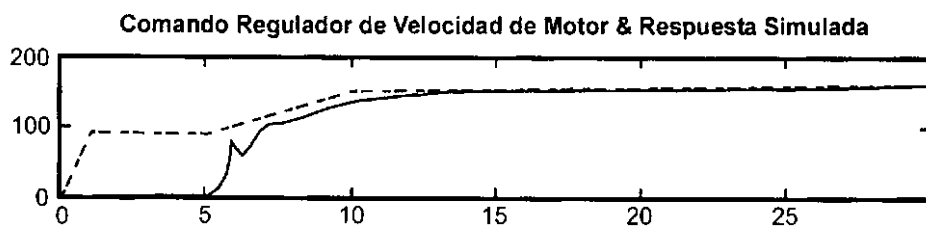


FIG. 3D

INDUCTION MOTOR TORQUE CONTROL IN A PUMPING SYSTEM

FIELD OF THE INVENTION

[0001] This invention generally relates to controlling the performance of an induction motor and, more particularly, to methods for controlling the performance of an induction motor used in a pumping system.

BACKGROUND OF THE INVENTION

[0002] In the oil and gas industry, an engine (e.g., a diesel, gasoline, natural gas, or propane engine) is sometimes used to power a three phase generator. The generator, in turn, supplies power to a three phase induction motor used to drive a mechanical pumping apparatus. If the induction motor in such a system is operated at variable speeds, the capability of the pumping system is greatly expanded. However, prior approaches to providing variable speed operation of the pump in such pumping systems have not been entirely satisfactory. In one previously used approach to operating a pump at variable speed in an engine driven pumping system, variable frequency and voltage power is delivered to a three phase motor driving the pump. Typically, in a system using a generator as the source of electrical power, an electronic variable speed drive (a.k.a., a variable frequency drive or VFD) is interposed between the generator and the induction motor to provide variable voltages and frequencies to the motor. There are many potential disadvantages to using a variable speed drive, including voltage harmonics generated on the motor leads that can damage the motor, current harmonics generated at the input of the VFD that can cause problems for the generator, the complexity in VFD design and/or the need for an expensive output transformer when higher voltages are used (most often when motor leads are very long).

[0003] To eliminate the need for a variable speed drive, some prior approaches employ a variable frequency power system that varies the speed and excitation of a three phase generator to produce a desired output frequency and voltage in an attempt to achieve the desired operation of the three phase motor in the pump. US patent number 7,170,262, to Pettigrew discloses a variable speed drive system of this type, and discusses the operation of such a system in comparison to earlier prior systems of the type using a variable speed drive as described herein above.

[0004] Unfortunately, variable frequency power systems, of the type exemplified by Pettigrew, have significant drawbacks. For example, simply attempting to control the output of the three phase generator may not produce the desired operation of the pump. The output speed of the induction motor driving the pump will vary based on factors such as pump loading. When that occurs, the user of such a variable frequency power system will not have accurate control of the pump speed and may encounter a variety of undesirable situations. For example, the pump may operate at a lower than expected speed, resulting in lower than optimal

production or the pump may operate at a higher than desired speed and experience a “pump dry” or “pump off” condition causing the pump to run without fluid to cool and lubricate it or the pump will turn off to allow the fluid to refill the casing, causing sediment to settle in the pump. These conditions will result in damage to the pump, resulting in reduced life.

[0005] The present invention is directed to overcoming the drawbacks described and, in addition, improving the state of the art in the oil and gas industry.

BRIEF SUMMARY OF THE INVENTION

[0006] In one embodiment, a system and method for controlling the rotational speed of a motor driving a pump is provided. By controlling the rotational speed of the motor instead of the frequency of the generator, the operation of the pump is more precisely and accurately controlled.

[0007] There is provided a system for controlling the speed of a motor driving a load. The motor is electrically connected to a generator which is driven by an engine. The generator includes a controllable field. The system includes a first control feedback loop configured to limit the difference between the magnetic flux in the rotor of the motor and a commanded level of magnetic flux wherein the magnetic flux in the rotor is estimated based on measurement of electrical inputs to the motor cables. A second control feedback loop is configured to limit the difference between the speed of the rotor of the motor and a commanded speed wherein the speed of the motor is estimated based on a measurement of electrical inputs to the motor cables.

[0008] There is further provided a method for controlling the speed of a motor driving a load. The motor is electrically connected to a generator which is driven by an engine. The generator includes a controllable field and the engine has a throttle. The method includes periodically performing the steps of measuring voltage and current inputs to the motor cables. Based on the measurements of voltage and current inputs to the motor cables, a signal is generated representing an estimate of rotor flux of the motor. The estimate of the rotor flux of the motor is compared to a flux rotor command signal are used to generate a signal representing the rotor flux error. The method further includes generating a flux excitation command signal based on the signal representing the rotor flux error with the flux excitation command signal controlling the excitation of the field of the generator. A signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor is generated. A comparison of the speed command signal with the signal representing an estimate of the speed of the motor is used to generate a signal representing the motor speed error. A throttle position command signal is generated based on the signal representing the motor speed error. A throttle position command signal is generated based on the signal representing the motor speed error with the throttle position command signal controlling the position of the throttle of the engine.

[0009] There is further provided a pump control system to control mechanical inputs to a pump. The pump is coupled to a electric motor and the electric motor is coupled to a generated driven by an engine. The pump control system includes an error control unit having a plurality of interface devices. A motor vector model is coupled to at least two of the interface devices. A rotor flux summation device is configured to provide a flux error estimate coupled to the motor vector model and one of the interface devices. A motor speed summation device coupled to the motor vector model and a motor speed error control is coupled to the motor speed summation device and one of the interface devices. The pump control system further includes a supervisory controller coupled to the motor speed summation device, the motor vector model, and the rotor flux summation device, wherein the speed of the motor coupled to the pump is controlled by a first control feedback loop configured to provide an excitation current command to the generator and a second control feedback loop configured to provide a throttle position command to the engine. In another embodiment, the pump control system includes an engine torque linearizer which is configured to linearize an engine torque command. The linearizer is coupled to at least one of the interface devices, the motor speed control and the motor vector model, wherein the system gain of the throttle position is near constant. During system start up, the supervisory control is configured to set a level of magnetic flux to reduce loading on the engine. In one embodiment, the supervisory controller sets the magnetic flux at zero during the system start up.

[0010] Other embodiments of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

[0012] FIG. 1 is an exemplary embodiment of an induction motor control system having an error control unit in accordance with the teachings of the present invention;

[0013] FIG. 2 is a block diagram of a Simulink software simulation performed on a system similar to the system of FIG. 1; and

[0014] FIG. 3A-3D are graphical depictions of the results from the simulation performed on the system of FIG. 2.

[0015] While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Referring now to FIG. 1, a pump control system 10 is illustrated. As will be more fully explained below, the error control system 20 of the pump control system 10 monitors one or more characteristics of the electrical input to the cables and motor 16 and, based on what is observed, calculates the mechanical inputs to the pump 18 and adjusts the operation of the engine 12 and generator 14. By controlling the mechanical inputs to the pump 18, the operation of the pump is more precise, accurate and dependable than would be provided by a system which only controls electrical outputs of a generator.

[0017] The engine 12 intake ingests air and fuel and, by combusting the mixture thereof, generates a rotary mechanical engine output 22. The rotary mechanical engine output 22 is dependent on the throttle position T_{xc} , fuel used, air temperature and density, etc. The engine 12 may operate using diesel, gasoline, liquid propane, natural gas or other types of fuels. The engine 12 is operably coupled to, and drives, the generator 14. In that regard, the rotary mechanical engine output 22 is typically directly coupled to the mechanical input of the generator 14. Even so, other types of connections such as gear boxes, belts, hydraulic power coupling and the like may be employed depending on the particular application. The generator 14 is a synchronous three phase generator, having a field which can be controlled.

[0018] The generator 14 is electrically coupled by electrical cables to a motor, which are collectively represented at 16. In the system shown, the pump is a centrifugal pump of the type known as an electrical submersible pump (ESP), so both the motor 16 and the pump 18 are disposed within a well casing far below ground level and the cables 16 are of considerable length. In a typical oil well, for example, the cables 16 may be thousands of feet long. Through the cables 16, the generator 14 supplies the motor 16 with electrical power. In the illustrated embodiment of FIG. 1, the motor 16 is a three phase induction motor. The electrical inputs to the motor 16 can be characterized by the voltages (V_m) and currents (I_m). The motor 16 generates a rotary mechanical output that may be characterized by pump speed (U_p) and pump torque (T_p).

[0019] The motor 16 is mechanically coupled to, and drives, the pump 18, which is situated at or near the bottom of the well casing and immersed or partially immersed in the fluid (e.g., oil and/or water) being pumped. The pump 18 generates a fluid output that may be characterized by, among other parameters, pump head (H_p) and pump flow (Q_p).

[0020] The error control unit 20 is, in general, in electrical communication with the engine 12 and the generator 14. The error control unit 20 is also configured to monitor the voltage inputs (V_m) and current inputs (I_m) to the cables and motor 16. The error control unit 20 includes interface devices 24, a motor vector model 26, a rotor flux summation device 28, a rotor flux error control 30, a motor speed summation device 32, and a motor speed error control 34. The error control unit 20 also optionally includes an engine torque linearizer 36.

[0021] The interface devices 24 are generally employed to manipulate or convert the signals and data sent or received by the error control unit 20. In that regard, the interface devices 24 can include numerous electrical components such as, for example, parallel input/output devices, analog to digital (A/D) converters, digital to analog (D/A) converters, current and voltage sensors, flux estimators, filters, integrators and the like.

[0022] In the embodiment shown, the interface devices 24 have two outputs. The first output is the throttle position command (T_{xc}), which is converted from the torque error command (T_{ec}) of the motor speed error control 34 or, in systems where the engine torque linearizer 36 is used, the linearized torque command output (T_{lc}) of the engine torque linearizer 36. The second output is the excitation current command (E_{ic}) which is converted from the flux error command (λ_{ec}) generated by the rotor flux error control 30.

[0023] For inputs, the interface devices 24 generate three motor voltage measurement signals (V_{mm}) to represent the voltages (V_m) on each phase of the cables and motor 16 and two motor current measurement signals (I_{mm}) to represent the currents (I_m) on two of the three phases. The current of the third phase is easily calculated, since the currents of the three phases must total zero, but could be measured as well.

[0024] The motor vector model 26 is in electrical communication with the interface devices 24, the rotor flux summation device 28, the supervisory controller 38, the motor speed summation device 32, and, when employed, the engine torque linearizer 36. The motor vector model 26 performs several mathematical functions using the motor voltage measurement signals (V_{mm}) and the motor current measurement signals (I_{mm}) in order to provide estimations as described in U.S. Patent No. 7,117,120 to Beck et al. (the '120 patent), which is included herein by reference. For example, the motor vector model 26 calculates and outputs estimates of the performance of the induction motor 16 including the motor speed at the motor shaft (U_{me}), the magnetic flux of the rotor (λ_{re}), and the mechanical torque of the motor shaft (T_{me}).

[0025] The rotor flux summation device 28 depicted in FIG. 1 receives two inputs, namely the rotor flux estimate (λ_{re}) from the motor vector model 26 and the rotor flux command (λ_{rc}) from the supervisory controller 38. During regular operation, the rotor flux command (λ_{rc}) is generally kept at a constant value to maintain proper torque (T_p) of the motor. However, during starting of the engine 12, the rotor flux command (λ_{rc}) may be greatly reduced or even held at zero to reduce the loading on the engine 12. Based on the inputs received, the rotor flux summation device 28 generates an output, namely the flux error estimate (λ_{ec}).

[0026] The flux error estimate (λ_{ec}) is received by the rotor flux error control 30. In general, the rotor flux error control 30 is a control loop structure designed to adjust its output to force the error term to zero. In the illustrated embodiment of FIG. 1, the rotor flux error control 30 is a proportional-integral-derivative (PID) controller. However, other types of control structures, such as proportional-integral (PI), fuzzy logic controllers, and the like, could be used

as is known in the art. The rotor flux error control 30 outputs the flux excitation command (λ_{ec}) to the interface devices 24.

[0027] The motor speed summation device 32 illustrated in FIG. 1 receives two inputs, namely the motor speed estimate (U_{me}) from the motor vector model 26 and the motor speed command (U_{mc}) from the supervisory controller 38. Based on the inputs received, the motor speed summation device 32 generates an output, namely the speed error estimate (U_{ee}).

[0028] The speed error estimate (U_{ee}) is received by the motor speed error control 34. In general, the motor speed error control 34 is a control loop structure designed to adjust its output to force the error term to zero. In the illustrated embodiment of FIG. 1, the motor speed error control 34 is a proportional-integral-derivative (PID) controller. However, other types of control structures, such as proportional-integral (PI), fuzzy logic controllers, and the like, could be used as is known in the art. As shown in FIG. 1, the motor speed error control 34 generates and sends the torque engine command (T_{ec}) to the optional engine torque linearizer 36. If the engine torque linearizer 36 is omitted from the error control unit 20, the torque engine command (T_{ec}) is provided directly to the interface devices 24.

[0029] When used, the engine torque linearizer 36 is used to ensure that a particular input is correlated with the appropriate and desired corrective action. For example, when a three percent (3%) change in engine torque is needed, a throttle change of ten percent (10%) may be required. In such circumstances, the engine torque linearizer 36 manipulates the engine torque command (T_{ec}) received from the motor speed error control 34 such that a linearized torque command (T_{lc}) is produced. Linearizing the torque command ensures that the system gain of the throttle position control is near constant and, therefore, easier to tune for optimum response. The linearized torque command (T_{lc}) is output to the interface devices 24 and provided to the engine 12. As such, the throttle position is changed as needed to correctly correspond to the engine torque command (T_{ec}). As shown in FIG. 1, the engine torque linearizer 36 receives two inputs, namely the engine torque command (T_{ec}) from the motor speed error control 34 and the motor speed estimate (U_{me}) from the motor vector model 26.

[0030] Still referring to FIG. 1, most of the components of the error control unit 20 are in electrical communication with the supervisory controller 38. In particular, the supervisory controller 38 delivers the motor speed command (U_{mc}) to the motor speed summation device 32 and the rotor flux command (λ_{rc}) to the flux rotor summation device 28. The values of these two commands may be derived by manual operator input, derived according to the methods described in the '120 patent, or derived by other automatic means. The supervisory controller 38 receives signals representing estimates of the motor speed at the motor shaft (U_{me}) and the mechanical torque of the motor shaft (T_{me}). The supervisory controller 38 also sets the programmable operating parameters (designated by the letter 'P' in a circle) for the interface devices 24, motor vector model 26, rotor flux error control 30, motor speed error control 34 and, when used, the engine torque linearizer 36. The programmable operating parameters include gains, filter coefficients, lookup table values, motor parameters and the like. The

supervisory controller 38 may also receive a variety of other inputs from the error control unit 20 and the system 10 and generate a variety of other outputs to the system 10.

[0031] In operation, the engine 12 within the system 10 is started while maintaining the rotor flux command (λ_{rc}) at or near zero. Some flux command is generally necessary to produce enough motor voltage (V_m) for the motor vector model 26 to be able to estimate motor speed (U_{me}). The stator speed of the motor 16 is determined by the motor vector module 26 using motor voltage measurement signals (V_{mm}) and (I_{mm}) representing, respectively, the voltages (V_m) and currents (I_m) of the phases of the cables and motor 16. Initially, the supervisory controller 38 also limits the calculated value of the slip of the motor 16 to zero (0) so that the calculated estimate of the motor speed (U_{me}) is the same as the electrical rotational speed of the stator of the motor 16 and, therefore, also proportional to the rotational speed of the engine 12.

[0032] The motor vector model 26 provides the motor speed estimate (U_{me}) to the supervisory controller 38. Once the motor speed estimate (U_{me}) reaches a predetermined or desired level, the controller ramps up the rotor flux command (λ_{rc}) at a desired rate. In determining the predetermined or desired level, the controller 38 may access and utilize a fixed parameter or one or more available look up tables. When a look up table is employed, the supervisory controller 38 uses the motor speed estimate (U_{me}) to locate the appropriate and corresponding flux rotor command (λ_{rc}) on the look up table. At this time, the supervisory controller 38 also increases, at a controlled rate, the limit on the calculated value of the slip of the motor 16 so that the calculated estimate of the motor speed (U_{me}) becomes the actual rotational speed of the motor 16 and pump 18.

[0033] The rotor flux summation device 28 compares the flux rotor command (λ_{rc}) with the flux rotor estimate (λ_{re}) provided by the motor vector model 26. Based on that comparison, the rotor flux summation device 28 generates the flux error estimate (λ_{ee}). The flux error estimate (λ_{ee}) is used by the rotor flux error control 30 where the flux excitation command (λ_{ec}) is determined. The flux excitation command (λ_{ec}) then passes through the interface devices 24 and is received by the generator 14 in the form of the excitation current command (E_{ic}). The excitation current command (E_{ic}) is received by and determines the field current of the generator 14 and changes the voltages (V_m) and currents (I_m) of the phases of the cables and motor 16. The process described above repeats at a predetermined frequency. As such, a first control feedback loop is operated.

[0034] At all times during operation, the motor speed summation device 32 compares the speed motor command (U_{mc}) with the speed motor estimate (U_{me}) received from the motor vector model 26 and generates the speed error estimate (U_{ee}).

[0035] Next, the speed error estimate (U_{ee}) is used by the motor speed error control 34 to generate the torque engine command (T_{ec}). The torque engine command (T_{ec}) is linearized by the engine torque linearizer 36 (when linearization is used) to generate the torque linearized

command (T_{lc}). The torque linearized command (T_{lc}) is transformed through the interface devices 24 and the throttle position command (T_{xc}) is produced and delivered to the engine 12. The process described above repeats at a predetermined frequency. As such, a second control feedback loop is operated.

[0036] The motor 16 driving the pump 18 operates based on the throttle position command (T_{xc}) and the excitation current command (E_{ic}). Therefore, the pump speed (U_p) and the pump torque (T_p) are accurately controlled and the pump head (H_p) and the pump flow (Q_p) precisely manipulated or held steady as needed for a particular application by the use of the first and second control feedback loops.

[0037] Those having skill in the art will appreciate that the invention thus overcomes the disadvantage experienced in prior approaches, such as Pettigrew, to providing variable pump speed control by removing or substantially reducing the possibility that the control of a generator will not translate into the desired operation of the motor and the pump. Indeed, the exemplary embodiment of the system 10 of FIG. 1, according to the invention, relies on controlling the torque of the motor instead of the often faulty assumption that the desired frequency output of the generator will result in the desired operation of the motor and the pump as in prior systems.

[0038] As an added advantage, the present invention, through precise control and ramping up of rotor flux, reduces the peak starting current drawn by the motor and, correspondingly, the current that needs to be provided by the generator. In prior systems where a generator is operated at a frequency and voltage and then the motor is switched on "across the line," motor current will peak at a value as much as one thousand percent (1000%) of the operating current of the motor. To handle such large starting currents, prior systems using this approach required many components in the system to be much larger and more robust than they would otherwise have needed to be. The present invention reduces the peak current to less than one hundred fifty percent (150%) of the motor's normal operating current, thereby substantially reducing the weight, complexity and cost of components required for practicing the invention.

[0039] In order to test and evaluate the system 10 (or a near equivalent thereof), a computer simulation was performed using the Simulink program developed by MathWorks. The set up and architecture of the simulation is schematically depicted in the block diagram 40 of FIG. 2.

[0040] The engine modeled in the simulation was a four cylinder engine from the Simulink demonstration parts. In addition, the motor speed error control 34 and the rotor flux error control 30 were proportional-integral (PI) controllers in the simulation. The simulation yielded the results depicted in FIGS. 3A to 3D. As can be seen in FIG. 3B, the peak current in the generator rotor and motor stator during starting was approximately 20 amperes, while the steady state peak currents were approximately 14 amperes. In FIG. 3C the rotor flux of the motor (solid line) is seen to converge smoothly on the rotor flux command (dashed line).

Further, in FIG. 3D, the motor speed (solid line) converged on and maintained at the commanded speed (dashed line).

[0041] All references, including publications, patent applications, and patents cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0042] For purposes of this disclosure, the term "coupled" means the joining of two components (electrical or mechanical) directly or indirectly to one another. Such joining may be stationary in nature or moveable in nature. Such joining may be achieved with the two components (electrical or mechanical) and any additional intermediate members being integrally formed as a single unitary body with one another or the two components and any additional member being attached to one another. Such adjoining may be permanent in nature or alternatively be removable or releasable in nature.

[0043] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) is to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. The term signal is to be construed as including all means of communicating data and/or information including, but not limited to data structures communicated between modules and subroutines in one or more computer programs, serial and parallel data transmission and analog signals. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0044] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible

variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

WHAT IS CLAIMED IS:

1. A system for controlling the speed of a motor driving a load, wherein the motor is electrically connected to a generator which is driven by an engine, said generator having a controllable field, said system comprising:

a first control feedback loop configured to limit the difference between the magnetic flux in the rotor of the motor and a commanded level of magnetic flux wherein the magnetic flux in the rotor is estimated based on measurement of electrical inputs to the motor cables; and

a second control feedback loop configured to limit the difference between the speed of the rotor of the motor and a commanded speed wherein the speed of the motor is estimated based on measurement of electrical inputs to the motor cables.

2. The system of claim 1, wherein, the motor delivers torque and the commanded level of magnetic flux is held substantially constant during regular operation of the system, to thereby maintain a substantially constant torque from the motor.

3. The system of claim 1, wherein, the motor delivers torque and the commanded level of magnetic flux is reduced during start-up of the system, to thereby reduce loading on the engine.

4. The system of claim 3, wherein, the commanded level of magnetic flux is reduced substantially to zero during start-up of the system.

5. The system of claim 1, wherein, the first and second control feedback loops are configured and operatively connected for:

measuring voltage and current inputs to the motor cables;

generating a signal representing an estimate of the rotor flux of the motor based on the measurements of the voltage and current inputs to the motor cables;

comparing a flux rotor command signal with the signal representing an estimate of the rotor flux of the motor to generate a signal representing the rotor flux error;

generating a flux excitation command signal based on the signal representing the rotor flux error, the flux excitation command signal controlling the excitation of the field of the generator;

generating a signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor;

comparing a speed command signal with the signal representing an estimate of the speed of the motor to generate a signal representing the motor speed error; and

generating a throttle position command signal based on the signal representing the motor speed error, the throttle position command signal controlling the position of the throttle of the engine.

6. The system of claim 5 further comprising:
generating a torque engine command; and

linearizing the torque engine command,
wherein the gain of the throttle position control is near constant and easier to tune for optimum response.

7. A method for controlling the speed of a motor driving a load, wherein the motor is electrically connected to a generator which is driven by an engine, said generator having a controllable field and said engine having a throttle, comprising periodically performing the steps of:

- measuring voltage and current inputs to the motor cables;
- generating a signal representing an estimate of the rotor flux of the motor based on the measurements of the voltage and current inputs to the motor cables;
- comparing a flux rotor command signal with the signal representing an estimate of the rotor flux of the motor to generate a signal representing the rotor flux error;
- generating a flux excitation command signal based on the signal representing the rotor flux error, the flux excitation command signal controlling the excitation of the field of the generator;
- generating a signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor;
- comparing a speed command signal with the signal representing an estimate of the speed of the motor to generate a signal representing the motor speed error; and
- generating a throttle position command signal based on the signal representing the motor speed error, the throttle position command signal controlling the position of the throttle of the engine.

8. The method of claim 7, wherein, the motor delivers torque and the method further comprises, holding the flux excitation command signal substantially constant during regular operation of the system, to thereby maintain a substantially constant torque from the motor.

9. The method of claim 7, wherein, the motor delivers torque and the method further comprises, reducing the flux excitation command signal during start-up of the system, to thereby reduce loading on the engine.

10. The method of claim 9, further comprising, reducing the flux excitation command signal during start-up of the system to substantially zero.

11. A pump control system to control mechanical inputs to a pump, the pump coupled to an electric motor, the electric motor coupled to a generator driven by an engine, the pump control system comprising:

- an error control unit including:
 - a plurality of interface devices;
 - a motor vector model coupled to at least two of the interface devices;

a rotor flux summation device configured to provide a flux error estimate coupled to the motor vector model and one of the interface devices;

a motor speed summation device coupled to the motor vector model; and

a motor speed error control coupled to the motor speed summation device and one of the interface devices; and

a supervisory controller coupled to the motor speed summation device, the motor vector model, and the rotor flux summation device,

wherein the speed of the motor coupled to the pump is controlled by a first control feedback loop configured to provide an excitation current command to the generator and a second control feedback loop configured to provide a throttle position command to the engine.

12. The pump control system of claim 11, further comprising an engine torque linearizer configured to linearize an engine torque command, the linearizer is coupled to at least one of the interface devices, the motor speed control and the motor vector model, wherein the system gain of the throttle position control is near constant.

13. The pump control system of claim 11, wherein during system startup the supervisory controller is configured to set a level of magnetic flux to reduce loading on the engine.

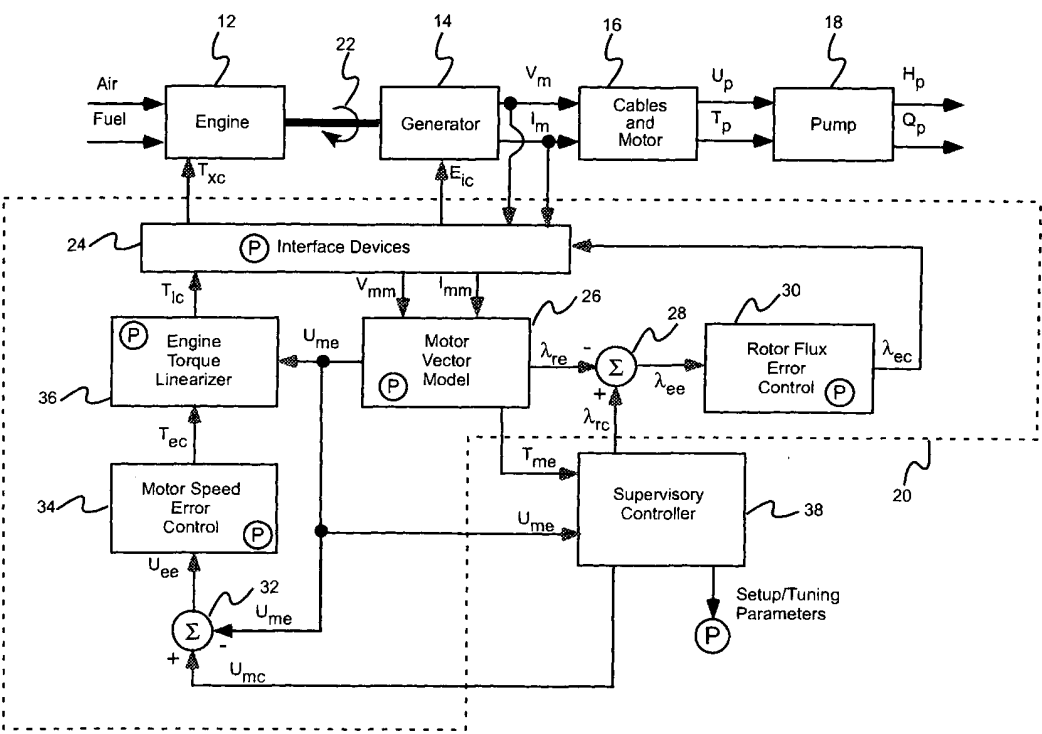
14. The pump control system of claim 13, wherein the magnetic flux is set at zero during system startup.

15. The pump control system of claim 11, further comprising the supervisory controller configured to program operating parameters for the interface devices, the motor vector model, the rotor flux error control, and the motor speed error control.

16. The pump control system of claim 12, wherein the engine torque linearizer is configured to be selectively programmed by the supervisory controller.

ABSTRACT

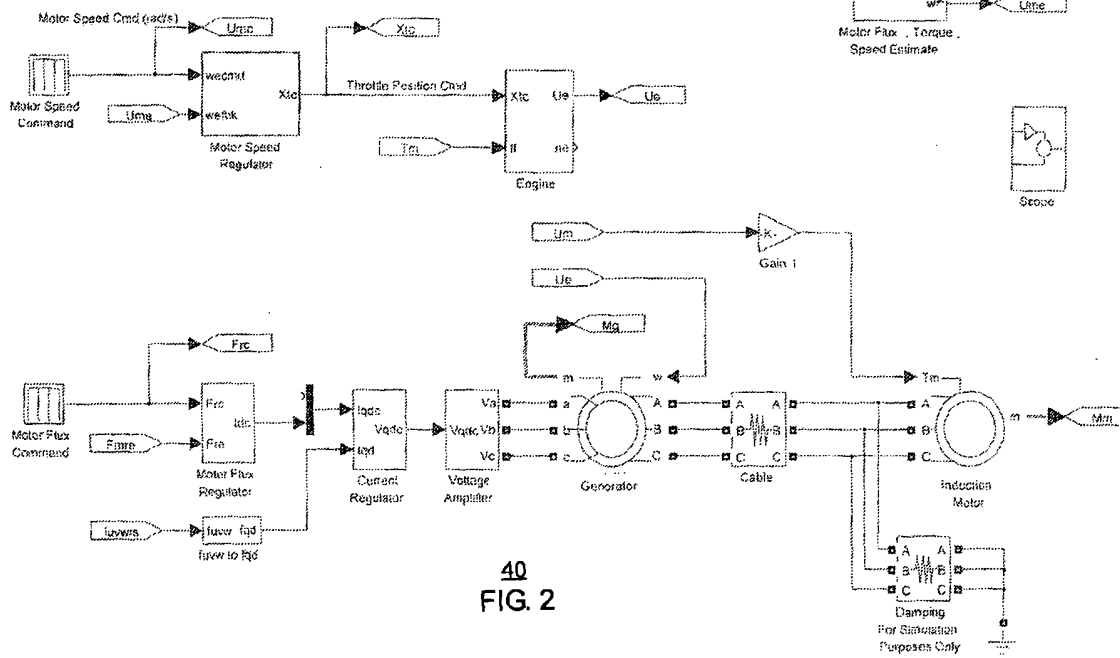
A system and method are provided for controlling the speed of a motor driving a load that is electrically connected to a generator driven by an engine, through use of a first control feedback loop configured to control the rotor flux of the motor by controlling the field excitation of the generator, and a second control feedback loop configured to control the speed of the motor by controlling the throttle position of the engine.



10
FIG. 1

VFG Control

Generator driving variable load induction motor
The motor flux reference is initially set to zero and the engine started to an initial speed. When the engine settles, the motor flux reference and motor speed are ramped up to a final set point.



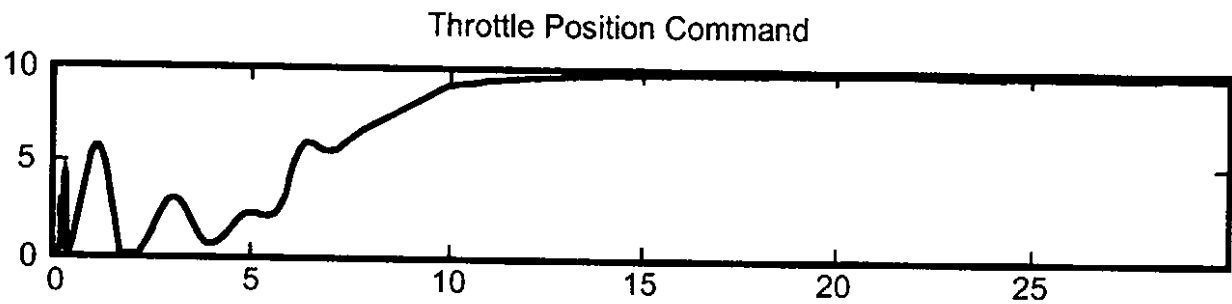


FIG. 3A

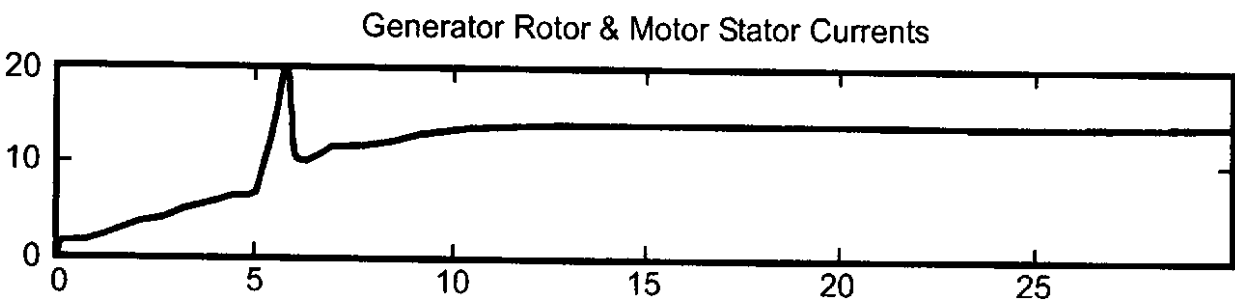


FIG. 3B

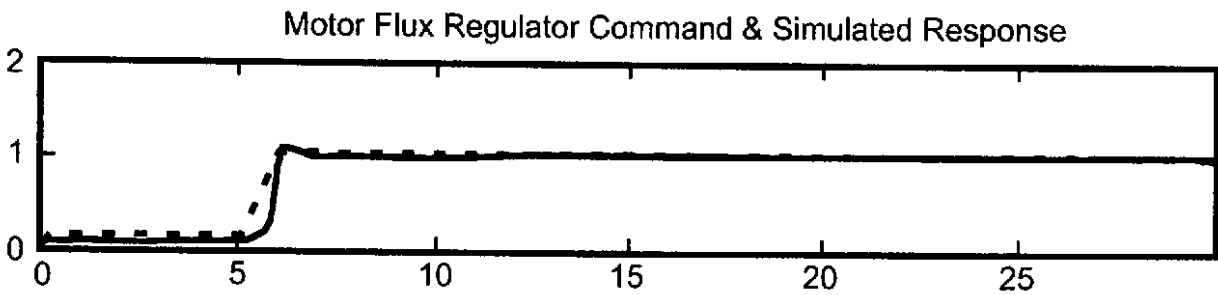


FIG. 3C

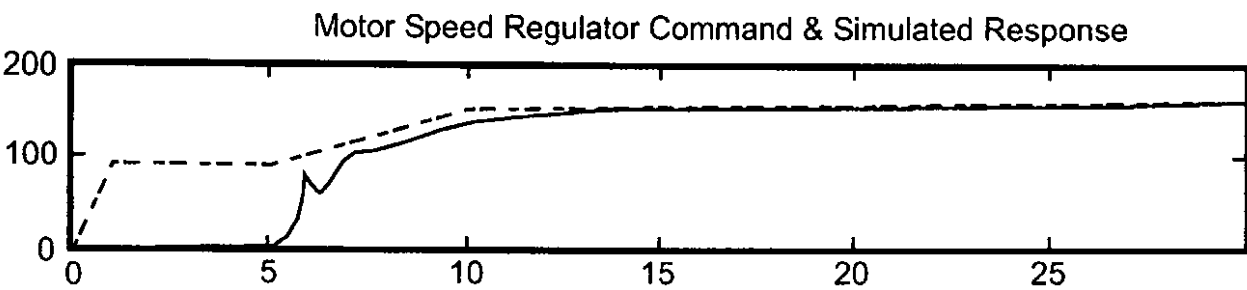


FIG. 3D

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 506614-PCT	FOR FURTHER ACTION see Form PCT/ISA/220 as well as, where applicable, item 5 below.	
International application No. PCT/US2010/027494	International filing date (day/month/year) 16 MARCH 2010 (16.03.2010)	(Earliest) Priority Date (day/month/year) 16 MARCH 2009 (16.03.2009)
Applicant UNICO, INC. et al		

This International search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the language, the international search was carried out on the basis of:

☒ the international application in the language in which it was filed

☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

b. ☐ This international search report has been established taking into account the rectification of an obvious mistake authorized by or notified to this Authority under Rule 91 (Rule 43.6bis(a)).

c. ☐ With regard to any nucleotide and/or amino acid sequence disclosed in the international application, see Box No. I.

2. ☐ Certain claims were found unsearchable (See Box No. II)

3. ☐ Unity of invention is lacking (See Box No. III)

4. With regard to the title,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the abstract,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the drawings,

a. the figure of the drawings to be published with the abstract is Figure No. 1

☒ as suggested by the applicant.

☐ as selected by this Authority, because the applicant failed to suggest a figure.

☐ as selected by this Authority, because this figure better characterizes the invention.

b. ☐ none of the figure is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/027494**A. CLASSIFICATION OF SUBJECT MATTER****F04B 49/06(2006.01)i, H02P 27/06(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04B 49/06; H02P 6/16; F04D 15/00; F02M 37/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: pump, motor, control, engine, generator

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-353624 A (AISIN SEIKI CO., LTD.) 16 December 2004 See paragraph [0020]-[0040], figure 1.	1-15
A	JP 2004-108296 A (KEIHIN CORP) 08 April 2004 See paragraph [0008]-[0013], figure 3.	1-15
A	JP 2007-211781 A (MITSUBISHI ELECTRIC CORP) 23 August 2007 See claims 1-5, figure 3.	1-15
A	JP 11-082316 A (HITACHI LTD.) 26 March 1999 See claims 1-5, figure 2.	1-15

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 SEPTEMBER 2010 (28.09.2010)

Date of mailing of the international search report

28 SEPTEMBER 2010 (28.09.2010)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-
gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

PARK, Heon Young

Telephone No. 82-42-481-8432



INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2010/027494

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2004-353624 A	16.12.2004	None	
JP 2004-108296 A	08.04.2004	None	
JP 2007-211781 A	23.08.2007	None	
JP 11-082316 A	26.03.1999	JP 4087931 B2	21.05.2008

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:
CROWE LAWRENCE

REINHART BOERNER VAN DEUREN P.C. 2215
PERRYGREEN WAY ROCKFORD IL 61107 USA

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43bis.1)

Date of mailing
(day/month/year) 28 SEPTEMBER 2010 (28.09.2010)

Applicant's or agent's file reference
506614-PCT

FOR FURTHER ACTION

See paragraph 2 below

International application No.

PCT/US2010/027494

International filing date (day/month/year)

16 MARCH 2010 (16.03.2010)

Priority date(day/month/year)

16 MARCH 2009 (16.03.2009)

International Patent Classification (IPC) or both national classification and IPC

F04B 49/06(2006.01); H02P 27/06(2006.01);

Applicant

UNICO, INC. et al

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☐ Box No. VIII Certain observations on the international application

2. FURTHER ACTION

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1bis(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
Government Complex-Daejeon, 139
Seonsa-ro, Seo-gu, Daejeon 302
-701, Republic of Korea
Facsimile No. 82-42-472-7140

Date of completion of this opinion

28 SEPTEMBER 2010 (28.09.2010)

Authorized officer

PARK, Hoon Young

Telephone No. 82-42-481-8432



WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.

PCT/US2010/027494

Box No. 1 Basis of this opinion

1. With regard to the language, this opinion has been established on the basis of:

- ☒ the international application in the language in which it was filed
- ☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

2. ☐ This opinion has been established taking into account the rectification of an obvious mistake authorized by or notified to this Authority under Rule 91 (Rule 43bis.1(a))

3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, this opinion has been established on the basis of:

a. a sequence listing filed or furnished

- ☐ on paper
- ☐ in electronic form

b. time of filing or furnishing

- ☐ contained in the international application as filed.
- ☐ filed together with the international application in electronic form.
- ☐ furnished subsequently to this Authority for the purposes of search.

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

**WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY**

International application No.

PCT/US2010/027494

Box No. V Reasoned statement under Rule 43bis.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1-15	YES
	Claims	NONE	NO
Inventive step (IS)	Claims	1-15	YES
	Claims	NONE	NO
Industrial applicability (IA)	Claims	1-15	YES
	Claims	NONE	NO

2. Citations and explanations :

Reference is made to the following documents:

D1: JP 2004-353624 A (AISIN SEIKI CO., LTD.) 16 December 2004
D2: JP 2004-108296 A (KEIHIN CORP) 08 April 2004
D3: JP 2007-211781 A (MITSUBISHI ELECTRIC CORP) 23 August 2007
D4: JP 11-082316 A (HITACHI LTD.) 26 March 1999

1. Novelty and Inventive Step

D1 relates to a motor-driven liquid pump comprising a control device (20), a liquid pump (11), a micro-computer (21), and an electric motor (12). D2 relates to a fluid pump system capable of keeping constant a feed fluid pressure without using a pressure sensor, a pressure regulator, or a part such as a return pipe. D3 relates to a motor control device for a water supply pump stopping a motor of the water supply pump when water in the water supply pump is used up. D4 relate to a variable speed control device for a pump drive motor in which the combined load characteristics of an inverter, motor, and pump in an area exceeding a commercial frequency are clarified and specified.

1.1 claims 1-6, claims 11-15

Each of independent claims 1 and 11 relates to a system for controlling the speed of a motor driving a load characterized by comprising a first control feedback loop, and a second control feedback loop. The first control feedback loop configures to limit the difference between the magnetic flux in the rotor of the motor and a commanded level of magnetic flux; the second control feedback loop configures to limit the difference between the speed of the rotor of the motor and a commanded speed.

None of the documents D1-D4, though directed to a device for controlling a pump, show the features of claim 1 or claim 11 mentioned above. Accordingly, claims 1 and 11 are not anticipated by any of the documents, nor are they obvious by the documents, taken alone or in combination.

Therefore, claim 1, claims 2-6 dependent on claim 1, claim 11, and claims 12-15 dependent on claim 11 meet the requirements of novelty and inventive step under PCT Article 33(2) and 33(3).

1.2 claims 7-10

Though independent claim 7 defines a method relating to a method for controlling the speed of a motor driving a load, the discussion on the novelty and inventive step of claim 1 is applicable because claim 7 shares the features of the claim 1 which is neither anticipated nor obvious by the prior art documents.

(Continued in Supplemental Box.)

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.

PCT/US2010/027494

Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of:

Box V

Therefore, claim 7, and claims 8-10 dependent on claim 7 meet the requirements of novelty and inventive step under PCT Article 33(2) and 33(3).

2. Industrial Applicability

Claims 1-15 meet the requirement of industrial applicability under PCT Article 33(4).

(43) International Publication Date
23 September 2010 (23.09.2010)



(10) International Publication Number
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(51) International Patent Classification:
F04B 49/06 (2006.01) *H02P 27/06* (2006.01)

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(21) International Application Number:
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(74) Agent: **CROWE, Lawrence**; Reinhart Boerner Van
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(22) International Filing Date:
16 March 2010 (16.03.2010)

(25) Filing Language: English

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(30) Priority Data:
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12/724,120 15 March 2010 (15.03.2010) US

(71) Applicant (for all designated States except US): **UNICO, INC.** [US/US]; 3725 Nicholson Road, Box 505,
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(72) Inventors; and

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[US/US]; 5117 41st Street, Kenosha, Wisconsin 53144
(US). **LUCAS, Michael O.** [US/US]; 2615 96th Street,
Franksville, Wisconsin 53126 (US). **MACDONALD, Michael A.**
[US/US]; 5110 Old Farm Road, Racine, Wis-

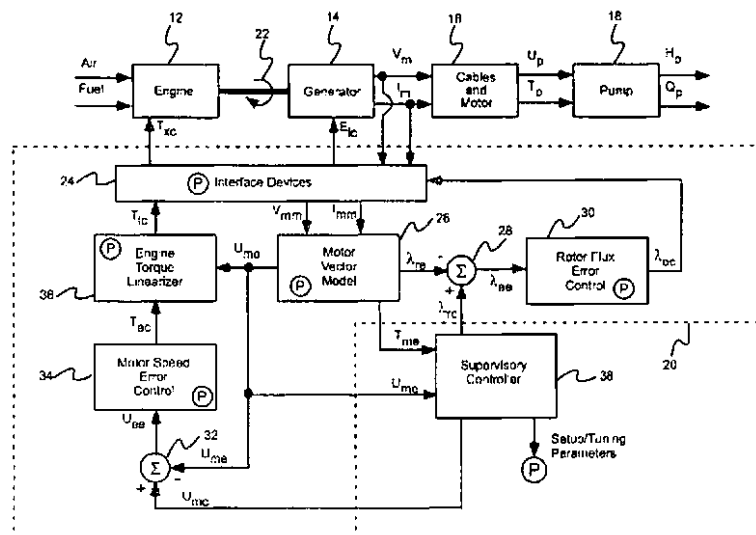
(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP,
KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD,
ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI,
NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD,
SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
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(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ,
TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE,
ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: INDUCTION MOTOR TORQUE CONTROL IN A PUMPING SYSTEM

FIG. 1



(57) Abstract: A system and method are provided for controlling the speed of a motor driving a load that is electrically connected to a generator driven by an engine, through use of a first control feedback loop configured to control the rotor flux of the motor by controlling the field excitation of the generator, and a second control feedback loop configured to control the speed of the motor by controlling the throttle position of the engine.



Published:

(88) Date of publication of the international search report:

— with international search report (Art. 21(3))

13 January 2011

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/027494**A. CLASSIFICATION OF SUBJECT MATTER****F04B 49/06(2006.01)i, H02P 27/06(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04B 49/06; H02P 6/16; F04D 15/00; F02M 37/08

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Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: pump, motor, control, engine, generator

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-353624 A (AISIN SEIKI CO., LTD.) 16 December 2004 See paragraph [0020]-[0040], figure 1.	1-15
A	JP 2004-108296 A (KEIHIN CORP) 08 April 2004 See paragraph [0008]-[0013], figure 3.	1-15
A	JP 2007-211781 A (MITSUBISHI ELECTRIC CORP) 23 August 2007 See claims 1-5, figure 3.	1-15
A	JP 11-082316 A (HITACHI LTD.) 26 March 1999 See claims 1-5, figure 2.	1-15

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 SEPTEMBER 2010 (28.09.2010)

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Name and mailing address of the ISA/KR

Korean Intellectual Property Office
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gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

PARK, Heon Young

Telephone No. 82-42-481-8432



INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2010/027494

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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JP 2004-108296 A	08.04.2004	None	
JP 2007-211781 A	23.08.2007	None	
JP 11-082316 A	26.03.1999	JP 4087931 B2	21.05.2008

(75) **Inventors/Applicants (for US only):** **BECK, Thomas L.** [US/US]; 16220 Durand Avenue, Union Grove, Wisconsin 53182 (US). **DRY, Michael D.** [US/US]; 2415 Floyd Drive, Racine, Wisconsin 53404 (US). **GARLOW, Mark E.** [US/US]; 5117 41st Street, Kenosha, Wisconsin 53144 (US). **LUCAS, Michael O.** [US/US]; 2615 96th Street, Franksville, Wisconsin 53126 (US). **MACDONALD, Michael A.** [US/US]; 5110 Old Farm Road, Racine, Wis-

(57) Abstract: A system and method are provided for controlling the speed of a motor driving a load that is electrically connected to a generator driven by an engine, through use of a first control feedback loop configured to control the rotor flux of the motor by controlling the field excitation of the generator, and a second control feedback loop configured to control the speed of the motor by controlling the throttle position of the engine.

WO 2010/107801 A2



Published:

- *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

INDUCTION MOTOR TORQUE CONTROL IN A PUMPING SYSTEM

FIELD OF THE INVENTION

[0001] This invention generally relates to controlling the performance of an induction motor and, more particularly, to methods for controlling the performance of an induction motor used in a pumping system.

BACKGROUND OF THE INVENTION

[0002] In the oil and gas industry, an engine (e.g., a diesel, gasoline, natural gas, or propane engine) is sometimes used to power a three phase generator. The generator, in turn, supplies power to a three phase induction motor used to drive a mechanical pumping apparatus. If the induction motor in such a system is operated at variable speeds, the capability of the pumping system is greatly expanded. However, prior approaches to providing variable speed operation of the pump in such pumping systems have not been entirely satisfactory. In one previously used approach to operating a pump at variable speed in an engine driven pumping system, variable frequency and voltage power is delivered to a three phase motor driving the pump. Typically, in a system using a generator as the source of electrical power, an electronic variable speed drive (a.k.a., a variable frequency drive or VFD) is interposed between the generator and the induction motor to provide variable voltages and frequencies to the motor. There are many potential disadvantages to using a variable speed drive, including voltage harmonics generated on the motor leads that can damage the motor, current harmonics generated at the input of the VFD that can cause problems for the generator, the complexity in VFD design and/or the need for an expensive output transformer when higher voltages are used (most often when motor leads are very long).

[0003] To eliminate the need for a variable speed drive, some prior approaches employ a variable frequency power system that varies the speed and excitation of a three phase generator to produce a desired output frequency and voltage in an attempt to achieve the desired operation of the three phase motor in the pump. US patent number 7,170,262, to Pettigrew discloses a variable speed drive system of this type, and discusses the operation of such a system in comparison to earlier prior systems of the type using a variable speed drive as described herein above.

[0004] Unfortunately, variable frequency power systems, of the type exemplified by Pettigrew, have significant drawbacks. For example, simply attempting to control the output of the three phase generator may not produce the desired operation of the pump. The output speed of the induction motor driving the pump will vary based on factors such as pump loading. When that occurs, the user of such a variable frequency power system will not have accurate control of the pump speed and may encounter a variety of undesirable situations. For example, the pump may operate at a lower than expected speed, resulting in lower than optimal production or the pump may operate at a higher than desired speed and experience a "pump dry" or "pump off" condition causing the pump to run without fluid to cool and lubricate it or the pump will turn off to allow the fluid to refill the casing, causing sediment to settle in the pump. These conditions will result in damage to the pump, resulting in reduced life.

[0005] The present invention is directed to overcoming the drawbacks described and, in addition, improving the state of the art in the oil and gas industry.

BRIEF SUMMARY OF THE INVENTION

[0006] In one embodiment, a system and method for controlling the rotational speed of a motor driving a pump is provided. By controlling the rotational speed of the motor instead of the frequency of the generator, the operation of the pump is more precisely and accurately controlled.

[0007] There is provided a system for controlling the speed of a motor driving a load. The motor is electrically connected to a generator which is driven by an engine. The generator includes a controllable field. The system includes a first control feedback loop configured to limit the difference between the magnetic flux in the rotor of the motor and a commanded level of magnetic flux wherein the magnetic flux in the rotor is estimated based on measurement of electrical inputs to the motor cables. A second control feedback loop is configured to limit the difference between the speed of the rotor of the motor and a commanded speed wherein the speed of the motor is estimated based on a measurement of electrical inputs to the motor cables.

[0008] There is further provided a method for controlling the speed of a motor driving a load. The motor is electrically connected to a generator which is driven by an engine. The generator includes a controllable field and the engine has a throttle. The method includes periodically performing the steps of measuring voltage and current inputs to the motor

cables. Based on the measurements of voltage and current inputs to the motor cables, a signal is generated representing an estimate of rotor flux of the motor. The estimate of the rotor flux of the motor is compared to a flux rotor command signal are used to generate a signal representing the rotor flux error. The method further includes generating a flux excitation command signal based on the signal representing the rotor flux error with the flux excitation command signal controlling the excitation of the field of the generator. A signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor is generated. A comparison of the speed command signal with the signal representing an estimate of the speed of the motor is used to generate a signal representing the motor speed error. A throttle position command signal is generated based on the signal representing the motor speed error. A throttle position command signal is generated based on the signal representing the motor speed error with the throttle position command signal controlling the position of the throttle of the engine.

[0009] There is further provided a pump control system to control mechanical inputs to a pump. The pump is coupled to a electric motor and the electric motor is coupled to a generated driven by an engine. The pump control system includes and error control unit having a plurality of interface devices. A motor vector model is coupled to at least two of the interface devices. A rotor flux summation device is configured to provide a flux error estimate coupled to the motor vector model and one of the interface devices. A motor speed summation device coupled to the motor vector model and a motor speed error control is coupled to the motor speed summation device and one of the interface devices. The pump control system further includes a supervisory controller coupled to the motor speed summation device, the motor vector model, and the rotor flux summation device, wherein the speed of the motor coupled to the pump is controlled by a first control feedback loop configured to provide an excitation current command to the generator and a second control feedback loop configured to provide a throttle position command to the engine. In another embodiment, the pump control system includes an engine torque linearizer which is configured to linearize an engine torque command. The linearizer is coupled to at least one of the interface devices, the motor speed control and the motor vector model, wherein the system gain of the throttle position is near constant. During system start up, the supervisory control is configured to set a level of magnetic flux to reduce loading on the engine. In one embodiment, the supervisory controller sets the magnetic flux at zero during the system start up.

[0010] Other embodiments of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

[0012] FIG. 1 is an exemplary embodiment of an induction motor control system having an error control unit in accordance with the teachings of the present invention;

[0013] FIG. 2 is a block diagram of a Simulink software simulation performed on a system similar to the system of FIG. 1; and

[0014] FIG. 3A-3D are graphical depictions of the results from the simulation performed on the system of FIG. 2.

[0015] While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Referring now to FIG. 1, a pump control system 10 is illustrated. As will be more fully explained below, the error control system 20 of the pump control system 10 monitors one or more characteristics of the electrical input to the cables and motor 16 and, based on what is observed, calculates the mechanical inputs to the pump 18 and adjusts the operation of the engine 12 and generator 14. By controlling the mechanical inputs to the pump 18, the operation of the pump is more precise, accurate and dependable than would be provided by a system which only controls electrical outputs of a generator.

[0017] The engine 12 intake ingests air and fuel and, by combusting the mixture thereof, generates a rotary mechanical engine output 22. The rotary mechanical engine output 22 is dependent on the throttle position T_{xc} , fuel used, air temperature and density, etc. The engine 12 may operate using diesel, gasoline, liquid propane, natural gas or other types of fuels. The engine 12 is operably coupled to, and drives, the generator 14. In that regard, the rotary mechanical engine output 22 is typically directly coupled to the mechanical input of the generator 14. Even so, other types of connections such as gear boxes, belts, hydraulic

power coupling and the like may be employed depending on the particular application. The generator 14 is a synchronous three phase generator, having a field which can be controlled.

[0018] The generator 14 is electrically coupled by electrical cables to a motor, which are collectively represented at 16. In the system shown, the pump is a centrifugal pump of the type known as an electrical submersible pump (ESP), so both the motor 16 and the pump 18 are disposed within a well casing far below ground level and the cables 16 are of considerable length. In a typical oil well, for example, the cables 16 may be thousands of feet long. Through the cables 16, the generator 14 supplies the motor 16 with electrical power. In the illustrated embodiment of FIG. 1, the motor 16 is a three phase induction motor. The electrical inputs to the motor 16 can be characterized by the voltages (V_m) and currents (I_m). The motor 16 generates a rotary mechanical output that may be characterized by pump speed (U_p) and pump torque (T_p).

[0019] The motor 16 is mechanically coupled to, and drives, the pump 18, which is situated at or near the bottom of the well casing and immersed or partially immersed in the fluid (e.g., oil and/or water) being pumped. The pump 18 generates a fluid output that may be characterized by, among other parameters, pump head (H_p) and pump flow (Q_p).

[0020] The error control unit 20 is, in general, in electrical communication with the engine 12 and the generator 14. The error control unit 20 is also configured to monitor the voltage inputs (V_m) and current inputs (I_m) to the cables and motor 16. The error control unit 20 includes interface devices 24, a motor vector model 26, a rotor flux summation device 28, a rotor flux error control 30, a motor speed summation device 32, and a motor speed error control 34. The error control unit 20 also optionally includes an engine torque linearizer 36.

[0021] The interface devices 24 are generally employed to manipulate or convert the signals and data sent or received by the error control unit 20. In that regard, the interface devices 24 can include numerous electrical components such as, for example, parallel input/output devices, analog to digital (A/D) converters, digital to analog (D/A) converters, current and voltage sensors, flux estimators, filters, integrators and the like.

[0022] In the embodiment shown, the interface devices 24 have two outputs. The first output is the throttle position command (T_{xc}), which is converted from the torque error command (T_{ec}) of the motor speed error control 34 or, in systems where the engine torque linearizer 36 is used, the linearized torque command output (T_{lc}) of the engine torque

linearizer 36. The second output is the excitation current command (E_{ic}) which is converted from the flux error command (λ_{ec}) generated by the rotor flux error control 30.

[0023] For inputs, the interface devices 24 generate three motor voltage measurement signals (V_{mm}) to represent the voltages (V_m) on each phase of the cables and motor 16 and two motor current measurement signals (I_{mm}) to represent the currents (I_m) on two of the three phases. The current of the third phase is easily calculated, since the currents of the three phases must total zero, but could be measured as well.

[0024] The motor vector model 26 is in electrical communication with the interface devices 24, the rotor flux summation device 28, the supervisory controller 38, the motor speed summation device 32, and, when employed, the engine torque linearizer 36. The motor vector model 26 performs several mathematical functions using the motor voltage measurement signals (V_{mm}) and the motor current measurement signals (I_{mm}) in order to provide estimations as described in U.S. Patent No. 7,117,120 to Beck et al. (the '120 patent), which is included herein by reference. For example, the motor vector model 26 calculates and outputs estimates of the performance of the induction motor 16 including the motor speed at the motor shaft (U_{me}), the magnetic flux of the rotor (λ_{re}), and the mechanical torque of the motor shaft (T_{me}).

[0025] The rotor flux summation device 28 depicted in FIG. 1 receives two inputs, namely the rotor flux estimate (λ_{re}) from the motor vector model 26 and the rotor flux command (λ_{rc}) from the supervisory controller 38. During regular operation, the rotor flux command (λ_{rc}) is generally kept at a constant value to maintain proper torque (T_p) of the motor. However, during starting of the engine 12, the rotor flux command (λ_{rc}) may be greatly reduced or even held at zero to reduce the loading on the engine 12. Based on the inputs received, the rotor flux summation device 28 generates an output, namely the flux error estimate (λ_{ec}).

[0026] The flux error estimate (λ_{ec}) is received by the rotor flux error control 30. In general, the rotor flux error control 30 is a control loop structure designed to adjust its output to force the error term to zero. In the illustrated embodiment of FIG. 1, the rotor flux error control 30 is a proportional-integral-derivative (PID) controller. However, other types of control structures, such as proportional-integral (PI), fuzzy logic controllers, and the like, could be used as is known in the art. The rotor flux error control 30 outputs the flux excitation command (λ_{ec}) to the interface devices 24.

[0027] The motor speed summation device 32 illustrated in FIG. 1 receives two inputs, namely the motor speed estimate (U_{me}) from the motor vector model 26 and the motor speed command (U_{mc}) from the supervisory controller 38. Based on the inputs received, the motor speed summation device 32 generates an output, namely the speed error estimate (U_{ee}).

[0028] The speed error estimate (U_{ee}) is received by the motor speed error control 34. In general, the motor speed error control 34 is a control loop structure designed to adjust its output to force the error term to zero. In the illustrated embodiment of FIG. 1, the motor speed error control 34 is a proportional-integral-derivative (PID) controller. However, other types of control structures, such as proportional-integral (PI), fuzzy logic controllers, and the like, could be used as is known in the art. As shown in FIG. 1, the motor speed error control 34 generates and sends the torque engine command (T_{ec}) to the optional engine torque linearizer 36. If the engine torque linearizer 36 is omitted from the error control unit 20, the torque engine command (T_{ec}) is provided directly to the interface devices 24.

[0029] When used, the engine torque linearizer 36 is used to ensure that a particular input is correlated with the appropriate and desired corrective action. For example, when a three percent (3%) change in engine torque is needed, a throttle change of ten percent (10%) may be required. In such circumstances, the engine torque linearizer 36 manipulates the engine torque command (T_{ec}) received from the motor speed error control 34 such that a linearized torque command (T_{lc}) is produced. Linearizing the torque command ensures that the system gain of the throttle position control is near constant and, therefore, easier to tune for optimum response. The linearized torque command (T_{lc}) is output to the interface devices 24 and provided to the engine 12. As such, the throttle position is changed as needed to correctly correspond to the engine torque command (T_{ec}). As shown in FIG. 1, the engine torque linearizer 36 receives two inputs, namely the engine torque command (T_{ec}) from the motor speed error control 34 and the motor speed estimate (U_{me}) from the motor vector model 26.

[0030] Still referring to FIG. 1, most of the components of the error control unit 20 are in electrical communication with the supervisory controller 38. In particular, the supervisory controller 38 delivers the motor speed command (U_{mc}) to the motor speed summation device 32 and the rotor flux command (λ_{rc}) to the flux rotor summation device 28. The values of these two commands may be derived by manual operator input, derived according to the methods described in the '120 patent, or derived by other automatic means. The supervisory controller 38 receives signals representing estimates of the motor speed at the motor shaft (U_{me}) and the mechanical torque of the motor shaft (T_{me}). The supervisory

controller 38 also sets the programmable operating parameters (designated by the letter 'P' in a circle) for the interface devices 24, motor vector model 26, rotor flux error control 30, motor speed error control 34 and, when used, the engine torque linearizer 36. The programmable operating parameters include gains, filter coefficients, lookup table values, motor parameters and the like. The supervisory controller 38 may also receive a variety of other inputs from the error control unit 20 and the system 10 and generate a variety of other outputs to the system 10.

[0031] In operation, the engine 12 within the system 10 is started while maintaining the rotor flux command (λ_{rc}) at or near zero. Some flux command is generally necessary to produce enough motor voltage (V_m) for the motor vector model 26 to be able to estimate motor speed (U_{me}). The stator speed of the motor 16 is determined by the motor vector module 26 using motor voltage measurement signals (V_{mn}) and (I_{mn}) representing, respectively, the voltages (V_m) and currents (I_m) of the phases of the cables and motor 16. Initially, the supervisory controller 38 also limits the calculated value of the slip of the motor 16 to zero (0) so that the calculated estimate of the motor speed (U_{me}) is the same as the electrical rotational speed of the stator of the motor 16 and, therefore, also proportional to the rotational speed of the engine 12.

[0032] The motor vector model 26 provides the motor speed estimate (U_{me}) to the supervisory controller 38. Once the motor speed estimate (U_{me}) reaches a predetermined or desired level, the controller ramps up the rotor flux command (λ_{rc}) at a desired rate. In determining the predetermined or desired level, the controller 38 may access and utilize a fixed parameter or one or more available look up tables. When a look up table is employed, the supervisory controller 38 uses the motor speed estimate (U_{me}) to locate the appropriate and corresponding flux rotor command (λ_{rc}) on the look up table. At this time, the supervisory controller 38 also increases, at a controlled rate, the limit on the calculated value of the slip of the motor 16 so that the calculated estimate of the motor speed (U_{me}) becomes the actual rotational speed of the motor 16 and pump 18.

[0033] The rotor flux summation device 28 compares the flux rotor command (λ_{rc}) with the flux rotor estimate (λ_{re}) provided by the motor vector model 26. Based on that comparison, the rotor flux summation device 28 generates the flux error estimate (λ_{ee}). The flux error estimate (λ_{ee}) is used by the rotor flux error control 30 where the flux excitation command (λ_{ec}) is determined. The flux excitation command (λ_{ec}) then passes through the interface devices 24 and is received by the generator 14 in the form of the excitation current command (E_{ic}). The excitation current command (E_{ic}) is received by and determines the

field current of the generator 14 and changes the voltages (V_m) and currents (I_m) of the phases of the cables and motor 16. The process described above repeats at a predetermined frequency. As such, a first control feedback loop is operated.

[0034] At all times during operation, the motor speed summation device 32 compares the speed motor command (U_{mc}) with the speed motor estimate (U_{me}) received from the motor vector model 26 and generates the speed error estimate (U_{ee}).

[0035] Next, the speed error estimate (U_{ee}) is used by the motor speed error control 34 to generate the torque engine command (T_{ec}). The torque engine command (T_{ec}) is linearized by the engine torque linearizer 36 (when linearization is used) to generate the torque linearized command (T_{lc}). The torque linearized command (T_{lc}) is transformed through the interface devices 24 and the throttle position command (T_{xc}) is produced and delivered to the engine 12. The process described above repeats at a predetermined frequency. As such, a second control feedback loop is operated.

[0036] The motor 16 driving the pump 18 operates based on the throttle position command (T_{xc}) and the excitation current command (E_{ic}). Therefore, the pump speed (U_p) and the pump torque (T_p) are accurately controlled and the pump head (H_p) and the pump flow (Q_p) precisely manipulated or held steady as needed for a particular application by the use of the first and second control feedback loops.

[0037] Those having skill in the art will appreciate that the invention thus overcomes the disadvantage experienced in prior approaches, such as Pettigrew, to providing variable pump speed control by removing or substantially reducing the possibility that the control of a generator will not translate into the desired operation of the motor and the pump. Indeed, the exemplary embodiment of the system 10 of FIG. 1, according to the invention, relies on controlling the torque of the motor instead of the often faulty assumption that the desired frequency output of the generator will result in the desired operation of the motor and the pump as in prior systems.

[0038] As an added advantage, the present invention, through precise control and ramping up of rotor flux, reduces the peak starting current drawn by the motor and, correspondingly, the current that needs to be provided by the generator. In prior systems where a generator is operated at a frequency and voltage and then the motor is switched on "across the line," motor current will peak at a value as much as one thousand percent (1000%) of the operating current of the motor. To handle such large starting currents, prior

systems using this approach required many components in the system to be much larger and more robust than they would otherwise have needed to be. The present invention reduces the peak current to less than one hundred fifty percent (150%) of the motor's normal operating current, thereby substantially reducing the weight, complexity and cost of components required for practicing the invention.

[0039] In order to test and evaluate the system 10 (or a near equivalent thereof), a computer simulation was performed using the Simulink program developed by MathWorks. The set up and architecture of the simulation is schematically depicted in the block diagram 40 of FIG. 2.

[0040] The engine modeled in the simulation was a four cylinder engine from the Simulink demonstration parts. In addition, the motor speed error control 34 and the rotor flux error control 30 were proportional-integral (PI) controllers in the simulation. The simulation yielded the results depicted in FIGS. 3A to 3D. As can be seen in FIG. 3B, the peak current in the generator rotor and motor stator during starting was approximately 20 amperes, while the steady state peak currents were approximately 14 amperes. In FIG. 3C the rotor flux of the motor (solid line) is seen to converge smoothly on the rotor flux command (dashed line). Further, in FIG. 3D, the motor speed (solid line) converged on and maintained at the commanded speed (dashed line).

[0041] All references, including publications, patent applications, and patents cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0042] For purposes of this disclosure, the term "coupled" means the joining of two components (electrical or mechanical) directly or indirectly to one another. Such joining may be stationary in nature or moveable in nature. Such joining may be achieved with the two components (electrical or mechanical) and any additional intermediate members being integrally formed as a single unitary body with one another or the two components and any additional member being attached to one another. Such adjoining may be permanent in nature or alternatively be removable or releasable in nature.

[0043] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) is to be construed to cover both the singular and the plural, unless otherwise indicated herein or

clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. The term signal is to be construed as including all means of communicating data and/or information including, but not limited to data structures communicated between modules and subroutines in one or more computer programs, serial and parallel data transmission and analog signals. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0044] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

WHAT IS CLAIMED IS:

1. A system for controlling the speed of a motor driving a load, wherein the motor is electrically connected to a generator which is driven by an engine, said generator having a controllable field, said system comprising:

a first control feedback loop configured to limit the difference between the magnetic flux in the rotor of the motor and a commanded level of magnetic flux wherein the magnetic flux in the rotor is estimated based on measurement of electrical inputs to the motor cables; and

a second control feedback loop configured to limit the difference between the speed of the rotor of the motor and a commanded speed wherein the speed of the motor is estimated based on measurement of electrical inputs to the motor cables.

2. The system of claim 1, wherein, the motor delivers torque and the commanded level of magnetic flux is held substantially constant during regular operation of the system, to thereby maintain a substantially constant torque from the motor.

3. The system of claim 1, wherein, the motor delivers torque and the commanded level of magnetic flux is reduced during start-up of the system, to thereby reduce loading on the engine.

4. The system of claim 3, wherein, the commanded level of magnetic flux is reduced substantially to zero during start-up of the system.

5. The system of claim 1, wherein, the first and second control feedback loops are configured and operatively connected for:

measuring voltage and current inputs to the motor cables;
generating a signal representing an estimate of the rotor flux of the motor based on the measurements of the voltage and current inputs to the motor cables;
comparing a flux rotor command signal with the signal representing an estimate of the rotor flux of the motor to generate a signal representing the rotor flux error;
generating a flux excitation command signal based on the signal representing the rotor flux error, the flux excitation command signal controlling the excitation of the field of the generator;

generating a signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor;

comparing a speed command signal with the signal representing an estimate of the speed of the motor to generate a signal representing the motor speed error; and
generating a throttle position command signal based on the signal representing the motor speed error, the throttle position command signal controlling the position of the throttle of the engine.

6. The system of claim 5 further comprising:
generating a torque engine command; and
linearizing the torque engine command,
wherein the gain of the throttle position control is near constant and easier to tune for optimum response.

7. A method for controlling the speed of a motor driving a load, wherein the motor is electrically connected to a generator which is driven by an engine, said generator having a controllable field and said engine having a throttle, comprising periodically performing the steps of:

measuring voltage and current inputs to the motor cables;
generating a signal representing an estimate of the rotor flux of the motor based on the measurements of the voltage and current inputs to the motor cables;
comparing a flux rotor command signal with the signal representing an estimate of the rotor flux of the motor to generate a signal representing the rotor flux error;
generating a flux excitation command signal based on the signal representing the rotor flux error, the flux excitation command signal controlling the excitation of the field of the generator;
generating a signal representing an estimate of the speed of the motor based on the measurements of the voltage and current inputs to the motor;
comparing a speed command signal with the signal representing an estimate of the speed of the motor to generate a signal representing the motor speed error; and
generating a throttle position command signal based on the signal representing the motor speed error, the throttle position command signal controlling the position of the throttle of the engine.

8. The method of claim 7, wherein, the motor delivers torque and the method further comprises, holding the flux excitation command signal substantially constant during regular operation of the system, to thereby maintain a substantially constant torque from the motor.

9. The method of claim 7, wherein, the motor delivers torque and the method further comprises, reducing the flux excitation command signal during start-up of the system, to thereby reduce loading on the engine.

10. The method of claim 9, further comprising, reducing the flux excitation command signal during start-up of the system to substantially zero.

11. A pump control system to control mechanical inputs to a pump, the pump coupled to an electric motor, the electric motor coupled to a generator driven by an engine, the pump control system comprising:

an error control unit including:

a plurality of interface devices;

a motor vector model coupled to at least two of the interface devices;

a rotor flux summation device configured to provide a flux error estimate coupled to the motor vector model and one of the interface devices;

a motor speed summation device coupled to the motor vector model; and

a motor speed error control coupled to the motor speed summation device and one of the interface devices; and

a supervisory controller coupled to the motor speed summation device, the motor vector model, and the rotor flux summation device,

wherein the speed of the motor coupled to the pump is controlled by a first control feedback loop configured to provide an excitation current command to the generator and a second control feedback loop configured to provide a throttle position command to the engine.

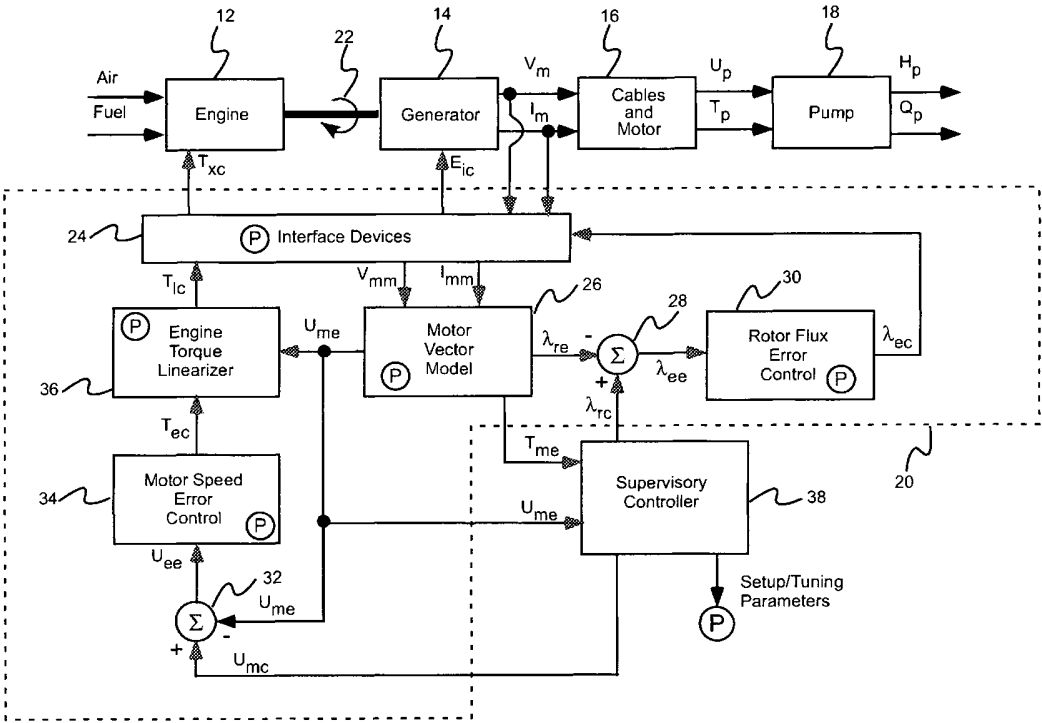
12. The pump control system of claim 11, further comprising an engine torque linearizer configured to linearize an engine torque command, the linearizer is coupled to at least one of the interface devices, the motor speed control and the motor vector model, wherein the system gain of the throttle position control is near constant.

13. The pump control system of claim 11, wherein during system startup the supervisory controller is configured to set a level of magnetic flux to reduce loading on the engine.

14. The pump control system of claim 13, wherein the magnetic flux is set at zero during system startup.

15. The pump control system of claim 11, further comprising the supervisory controller configured to program operating parameters for the interface devices, the motor vector model, the rotor flux error control, and the motor speed error control.

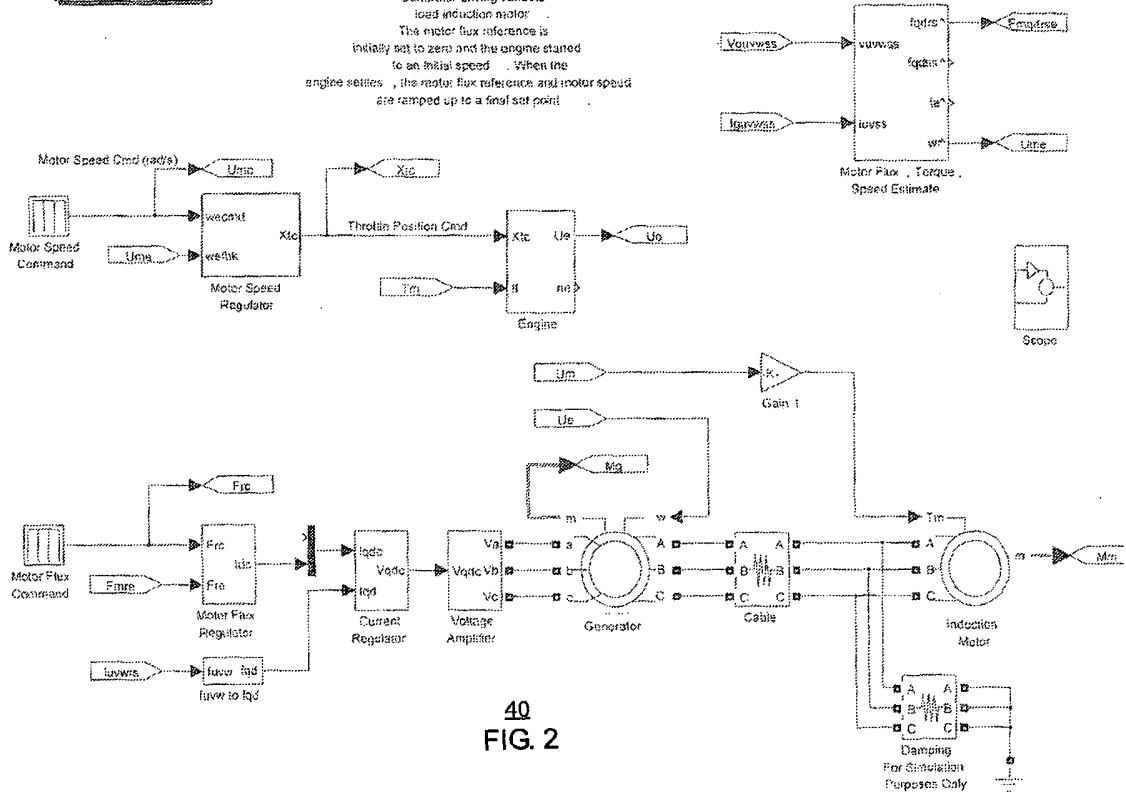
16. The pump control system of claim 12, wherein the engine torque linearizer is configured to be selectively programmed by the supervisory controller.



10.
FIG. 1

VFG Control

Generator driving variable
load induction motor
The motor flux reference is
initially set to zero and the engine started
to an initial speed. When the
engine settles, the motor flux reference and motor speed
are ramped up to a final set point.



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FIG. 2

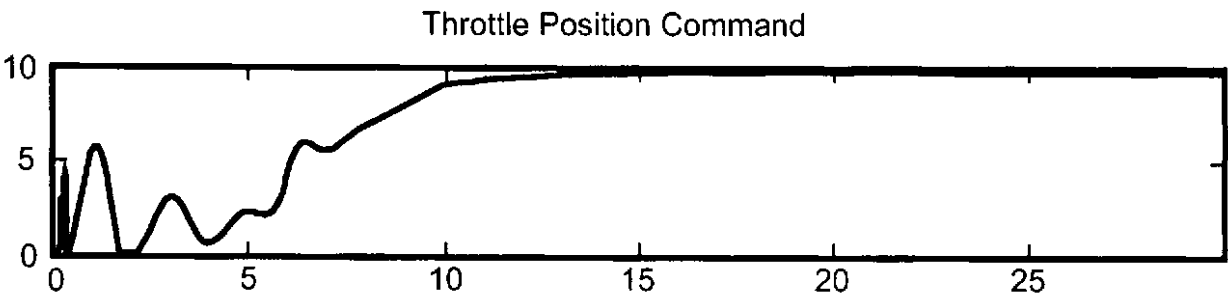


FIG. 3A

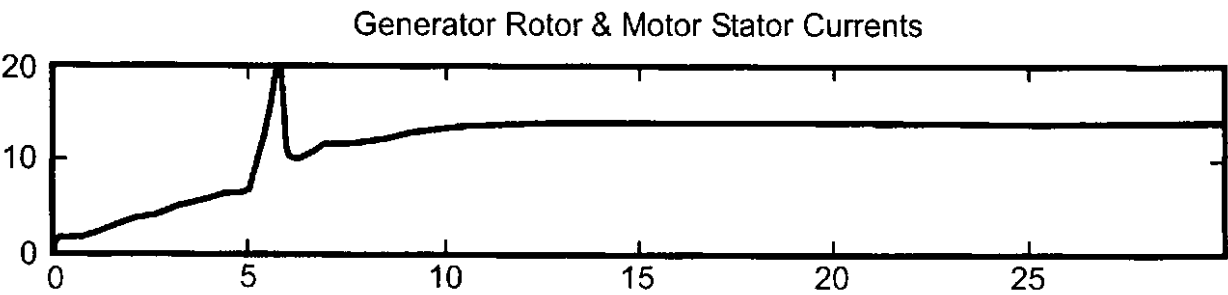


FIG. 3B

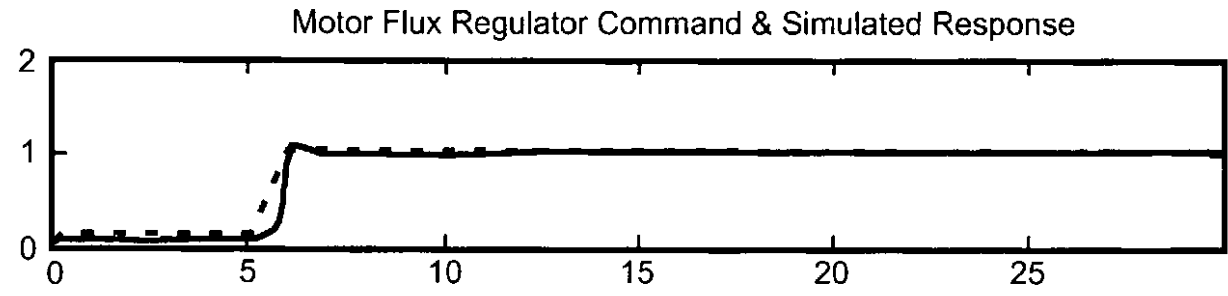


FIG. 3C

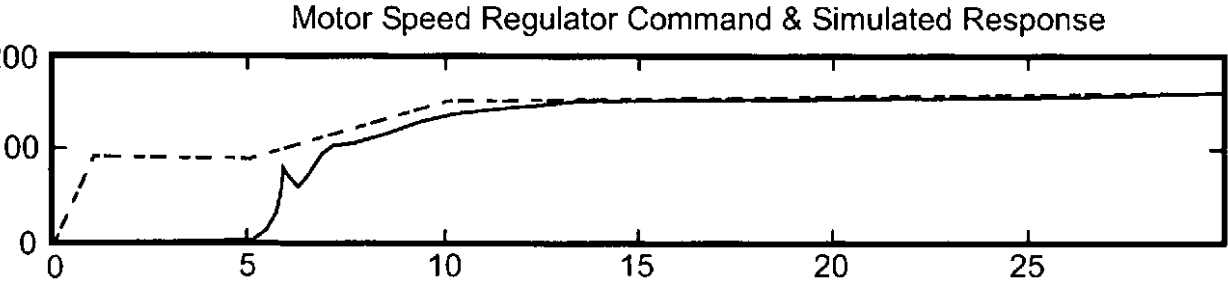
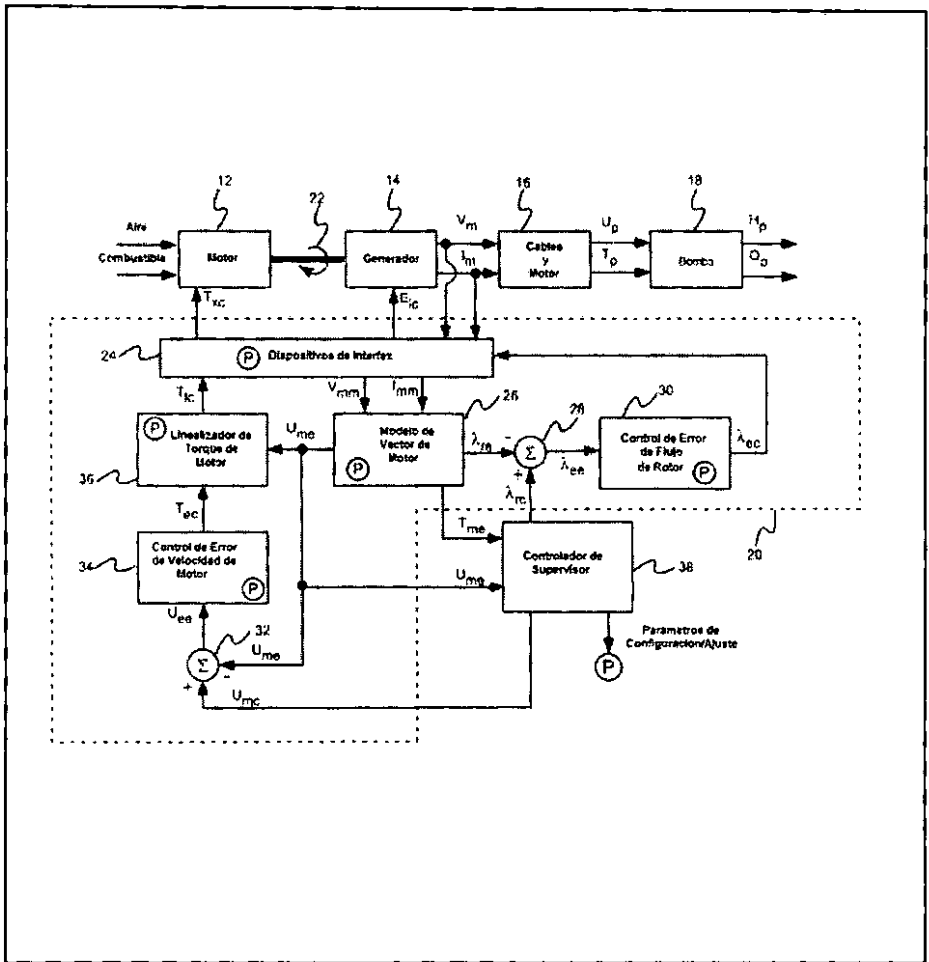
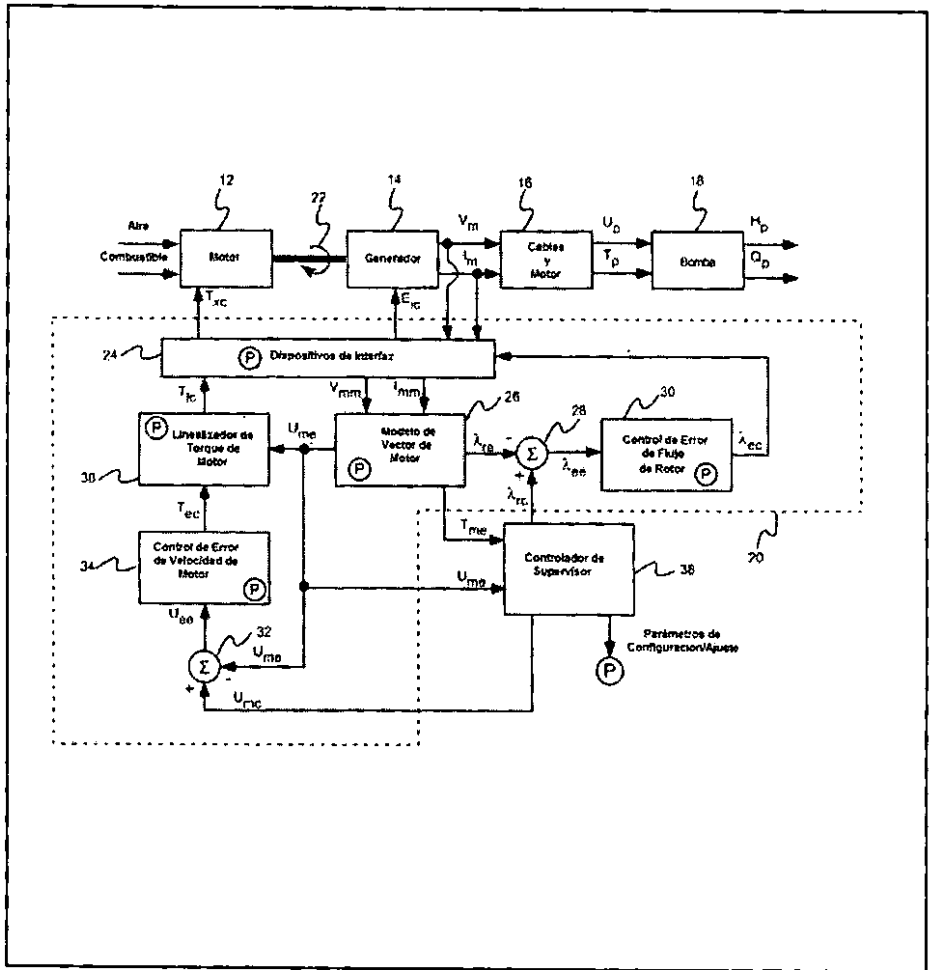


FIG. 3D





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Act. 411 PRESENTACION Folios: 84

PATENTE DE INVENCION ☐

MODELO

☐	Indicación que se solicita una patente.
☐	Datos de identificación del solicitante o de la persona que presenta la solicitud
☐	Descripción de la invención
☐	Dibujos de ser estos pertinentes
☐	Comprobante de pago de las tasas establecidas (De ser el caso formato de descuento)
Completa ☐	Incompleta ☐

PATENTE DE INVENCION PCT ☒

MODELO DE UTILIDAD PCT ☐

Art.33 Decisión 486/00, Circular Única

☒	Indicación que se solicita una PCT
☒	Copia de la solicitud en español, tal como fue presentada inicialmente (capítulo descriptivo, reivindicatorio, resumen)
☒	Dibujos de ser estos pertinentes
☒	Comprobante de pago de las tasas establecidas (de ser el caso formato de descuento)
Completa ☐	Incompleta ☐

DISEÑO INDUSTRIAL ☐

(Art. 119 Decisión 486/00)

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☐	Datos de identificación del solicitante o de la persona que presenta la solicitud
☐	Representación gráfica y fotográfica del Diseño industrial o muestra del material que incorpora el diseño
☐	Comprobante de pago de las tasas establecidas
Completa ☐	Incompleta ☐

ESQUEMA DE TRAZADO ☐

(Art. 92 Decisión 486/00)

☐	Indicación que se solicita un esquema de trazado
☐	Datos de identificación del solicitante o de la persona que presenta la solicitud
☐	Representación gráfica de un esquema de trazado
☐	Comprobante de pago de las tasas establecidas
Completa ☐	Incompleta ☐