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LOAD SIDE DYNAMIC BEHAVIOUR OF WIND ENERGY / ISOLATED LOAD SYSTEM DURING SYNCHRONIZATION AND LOAD VARIATION

السلوك الديناميكي على جانب الحمل لنظام طاقة رياح يغذي حملاً معزولاً أثناء عملية التزامن و تغيير الحمل.

BY

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الخلاصة : من خصائص الطاقة الكهربية المولدة من طاقة الرياح بإستخدام مولد التيار المتردد ، تغير الجهد و التردد مع تغير السرعة - لذا يكون من الضروري العمل على تثبيت الجهد والتردد عند تغذية تلك الطاقة إلى حمل معزول عن الشبكة العامة. يقدم البحث نموذجاً رياضياً لنظام مؤسس على الربط بواسطة التيار المستمر بين أطراف المولد متغير السرعة وأطراف الحمل المعزول ، حيث يعطي المولد الطاقة إلى موحد محكوم يتصل من خلال ممانعة تنعيم بأطراف "مغير إستاتيكي" يعطي الطاقة المحولة إلى الحمل بجهد و تردد ثابتين. يتم إشعال المغير بنبضات غير محكومة تتفق مع التردد المطلوب للحمل وذلك بمساعدة معوض تزامني ذو تغذية محكومة يقوم بإمداد كل من المغير و الحمل بالقدرة غير الفعالة اللازمة لهما. يهتم النموذج الرياضي و القائم على ثلاث معادلات تفاضلية من الدرجة الأولى غير خطية بالأداء الديناميكي للنظام خاصة عقب إجراء التزامن اللازم للمغير وأيضاً عقب التغير الفاجئ للحمل ، ويتم إعداد القيم الأولية للمتغيرات الداخلة في تلك المعادلات من لحظة إلى أخرى بناء على المنحنى الإتجاهي للنظام و القائم على " القيم الفعالة المتاورة " و إتخاذ نبضات المغير الإستاتيكي" مرجعاً للإسناد " تهتز بالنسبة له جميع المتغيرات الأخرى.

وقد أوضحت نتائج البرنامج المكتوب للحاسب الآلي ضرورة إستخدام " نظام بطاريا " لإختزان الطاقة الفعالة الزائدة أو تعويض النقص فيها عند إهتزاز النظام وضرورة إختيار القيم المثلى لعناصر المعوض التزامني و ممانعة التنعيم خاصة مقاومة ملفات الإخماد بالمعوض وذلك للإقلال من الإهتزازات عقب عملية التزامن و التغير الفاجئ للحمل. كما يجب أن يكون الإنزلاق صغيراً بين نبضات المغير وتردد الجهد على أطرافه ، وحساب القيم البدئية "للزاوية التقدمية للمغير" بدقة لكي تتناسب مع جهود المغير ، وذلك لإتمام التزامن بنجاح. كما أوضحت النتائج أيضاً ضرورة التحكم المستمر في الطاقة غير الفعالة المستمدة من المعوض ، للحفاظ على الجهود على طرفي المغير ثابتة و العمل عند أقل قيمة للزاوية التقدمية وذلك للإقلال من الطاقة غير الفعالة اللازمة للمغير - بما يمكن الحفاظ على التشغيل المستقر للنظام.

Abstract :

The power gained by a wind-turbine driven alternator or induction generator is characterised by its variable voltage and frequency. The stablisation of both variables is preferably done using a DC-link ; especially when the converted power is supplied to an isolated load. A controlled rectifier receives this power to deliver it to the DC-link inverter. This inverter is uncontrolled and triggered by rigid impulses whose frequency corresponds to the required load frequency. It delivers the DC-link power to the isolated load at fixed frequency and constant voltage with the help of a controlled excitation synchronous compensator. The system arising according to this configuration is very sensetive to any sudden disturbances. This paper is concerned with the dynamic behaviour of this system ; especially in case of synchronization and load variation.

For this purpose a relevant mathematical model has been developed using the MATLAB software. The modelling is based mainly on three first order, non-linear differential equations. Their iterative solution requires the determination of additional group of indirect variables ; interval by interval. This determination is carried out using a quasi-oscillated phasor diagram with time varying effective values ; assuming the rigid impulse as reference. The results show the necessity of continuous control of the voltages on both sides of the inverter, by controlling the rectifier and the compensator excitation. Thereby the advance angle of the inverter can be held constant at a reasonable value in order to minimize its reactive power demand. Also, it is necessary to optimize the computer damper parameters, as well as the DC-link parameters, in order to get stable operation and to prevent system failures.

1. INTRODUCTION :

The increasing rate of depletion of conventional energy resources and ability of electrical generators to convert mechanical power over a wide range of rotor speeds has been given rise to an interest in the possible contribution of wind energy to provide fuel displacement [1,2]. Economy is the factor to compare between using AC or DC generator. For output power less than 0.5 MVA, it is found that both DC generator and AC generator with rectifier are the same economically [4]. But for more higher power, the AC generator with rectifier is preferred. Also, the induction generator has been found to be very appropriate than the three phase alternator for wind energy application due to its low unit cost, reduced maintenance, rugged and brush less rotor (squirrel-cage type) , etc. [3].

Naturally, the conversion of wind energy through a variable speed generator is faced with many problems, such as the variable voltage and frequency at the utility terminals. One of the more adequate solutions of these problems is the use of a DC-link. Thereby, the converted wind energy can be supplied at fixed frequency and to great extant at constant voltage. Another important problem, especially for isolated utilities, is the necessity of a reactive power supply at the inverter output terminals. In this direction, an advantageous-full solution will be the use of a synchronous compensator

According to the above concepts, the paper presents an interfacing system ,Fig.(1), which ensure a good match between the converted wind energy and the load demand, under constant frequency and stabilized voltage.

The main object of this paper is the development of a mathematical model which represents suitably the proposed system configuration and makes it possible to get its dynamic behaviour. The effect of some pre-chosen system parameters, such as L_d and R_{damp} , on this behaviour is taken into consideration ; especially under the following conditions :

(a) Synchronizing the system at light load.

(b) Sudden increase or decrease of load at different load power factors.

2. SYSTEM CONFIGURATION AND SYNCHRONIZATION :

The system built is shown in Fig.(1). The DC-link receives the power of a controlled rectifier to deliver it to an uncontrolled inverter. According to the control strategy, discussed later, the rectifier can be directed to held the DC voltage V_{DR} or V_{DI} behind the smoothing reactor or the inverter ; respectively, constant. The thyristors of the inverter-bridge are triggered by independent rigid impulses according to the required load frequency. By this type of steering, the inverter frequency can be hold constant. It is assumed in this system that the inverter delivers the active power transmitted over the DC-link to an isolated load. The reactive power demand of both load and inverter is supplied by the synchronous compensator connected to the inverter AC-side. In addition to the delivery of reactive power, this type of compensator is able to ensure :

(1) Natural commutation of the inverter.

(2) Constant AC voltage,V, across the inverter and load ; through a controlled excitation.

(3) Existence of a stand-by power supply in emergency cases ; when the wind power cuts off

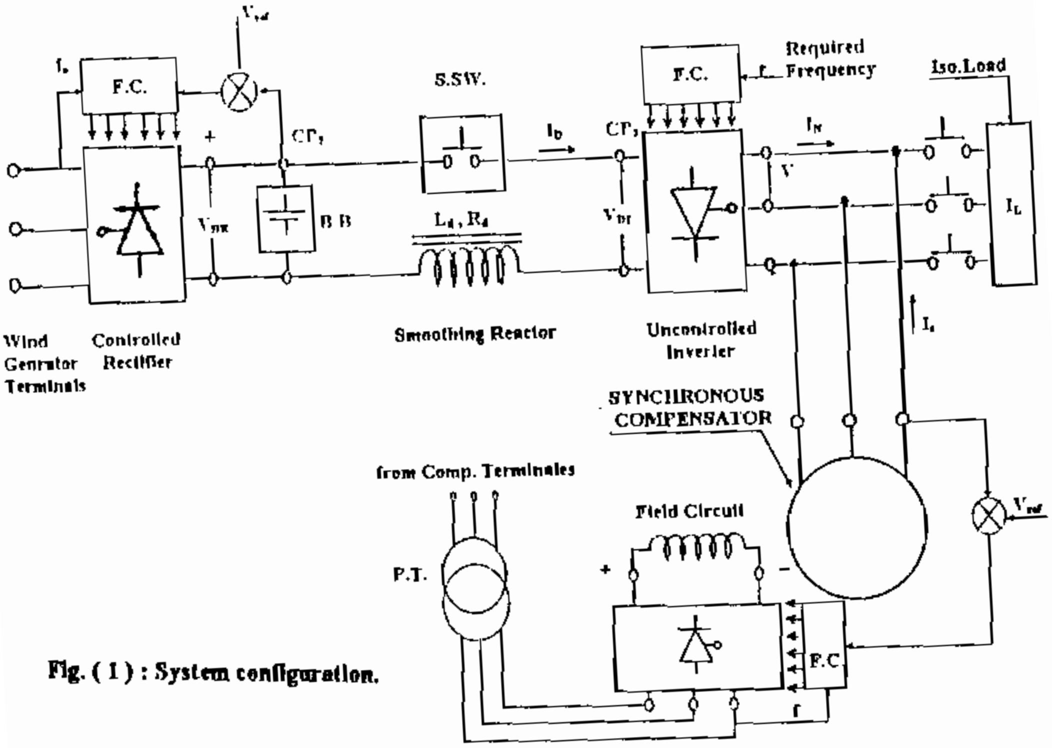


Fig. (1) : System configuration.

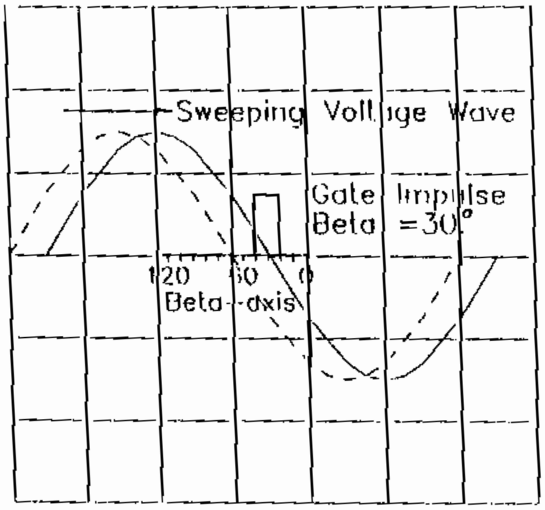


Fig. (2) : Simulated oscillograph of synchronizing instant.

The battary-bank (B.B.) is shunted to the DC-link at either the control points cp1 or cp2 to activate under the DC voltage V_{DR} or V_{DI} ; respectively. It acts as a reservoir for excess wind energy or to support any temporary lack of this energy. Due to the slip which may be existed between the frequency of the rigid impulses and the frequency of the AC-voltage applied initially to the inverter terminals, as shown in Fig.(2), a synchronization process must be carried out before the shut-on of the synchronizing switch (S.SW.). This process can be directly or indirectly done [6]. For the proposed system, the direct synchronization method is preferred. According to this method, the following conditions must be first fulfilled :

1. Identical polarity across the synchronizing switch.
2. Equal potential across the synchronizing switch, this means :

$$V_{DR} = V_{DI} = \frac{3\sqrt{6}}{\pi} V \cos \beta_0$$

where, β_0:= initial value of the inverter advance angle.

3. Proper instant of synchronization.

Any deviation of the value of V_{DI} from the value of V_{DR} can be corrected by adjusting the terminal AC-voltage V through the excitation of the synchronous machine. In this case the machine is running as a generator with the help of an auxiliary motor. The choice of the proper instant to close the synchronizing switch can be done with the help of an oscilloscope. The sweeping speed of the voltage wave in either of the two directions can be minimized by adjusting the auxiliary motor speed. Afterthat, the proper instant can be catched when the impulse signal overlaps the zero value of the voltage-wave. Just S.SW. is closed, the auxiliary motor must be disconnected. The experience shows that the system may run out of synchronism due to one of the three following reasons :

1- Large slip ; it must be within 0.001 .
2- Damping effects of the synchronous machine are not large enough.
3- Applied load is too small or open.

Therefore, the expected dynamic behaviour of the system as a subsequent response due to synchronization must be determined and discussed.

3. MATHEMATICAL SIMULATION :

In order to investigate the dynamic behaviour of the proposed system, it follows now the representation policy and the control strategies which are considered, while deriving the mathematical model.

3.1 Representation Policy :

As the static convertors (rectifiers and inverters) can not be directly represented by RLC parameters, the mathematical model of the proposed system will not linearly derived. In this system, either the rectifier or the inverter can be considered as a uni-directional device ,which couples the generator side to the DC-link, or the DC-link to the load side ; respectively. Both the generator and load sides are operating with different frequencies. Therefore, it seems difficult to get a unified mathematical model for such non-homogeneous system.

The representation policy which will be followed depends on the system discoupling at the convertors into three regions : the generator-side , the DC-link , and the load-side including the compensator. The mathematical simulation of each region can be individually obtained and then integrated with the others at the terminals of the relevant converter by applying the corresponding equilibrium relations. These relations relate either the currents or voltages on both sides of the converter to each other. In accordance with convertor power, it is assumed that the input power is equal to the output.

According to this policy, the mathematical model of the proposed system has been deriven under the following assumptions :

1. Saturation and higher harmonics are neglected.
2. Commutation effects on the inverter current shape are neglected. This current is assumed to be rectangular and only its fundamental is considered.
3. All variables are represented by their time varying effective values.
4. The voltage and power on the AC-side of the rectifier are assumed to be constant during any disturbance on the AC-side of the inverter.

3.2. Control Strategies :

The mathematical model assumes three different control strategies or types. They can be identified as :

Control Type (1) :

Both the rectifier and the compensator excitation are controlled to hold the voltages across both sides of the inverter, V_{DI} and V, constant. This strategy enables the inverter to operate at constant advance angle β . In turn, its power factor angle φ_N is expected to be nearly constant.

Control Type (2) :

Both the rectifier and the compensator excitation are controlled to get constant voltage, V_{DR} , behind the smoothing reactor and constant V. It is expected according to this strategy that the advance angle β will vary within a too limitted range.

Control Type (3) :

The rectifier is controlled to get constant voltage, V_{DR} , behind the smoothing reactor ; while the compensator excitation is uncontrolled. It is expected here that the terminal voltage V, as well as the advance angle β , will vary within a too wide range.

3.3. Mathematical Model :

According to the above policy and assumptions , the following three non-linear differential equations can be considered :

$$\dot{I}_D = \frac{d}{dt}(I_D) = (V_{DR} - R_d . I_D - V_{DI}) / L_d \qquad (1)$$

$$\dot{\omega}_\pi = \frac{d}{dt}(\omega_\pi) = \frac{P}{j . \omega_o} . (T_s + T_m - T_{db}) \qquad (2)$$

$$\dot{\xi} = \frac{d}{dt}(\xi) = \omega_o (1 - \omega_\pi) \qquad (3)$$

The first equation is derived for the DC-link voltage equation, where :

V_{OR} := DC voltage behind smoothing reactor.

$$= V_{DI} + R_d . I_D + L_d . \dot{I}_O \qquad = f(V_{DI} , I_O , \dot{I}_O) \qquad (1-1)$$

V_{DI} := DC voltage behind inverter.

$$= 3 . \frac{\sqrt{6}}{\pi} . V \cos\phi_N . \cos\frac{\gamma_N}{2} = f(V , \phi_N , \gamma_N) \qquad (1-2)$$

The second one ,Eq.(2), is the dynamic equation of the synchronous compensator, where :

T_s := Electric developed synchronous torque .

$$= \frac{3.P}{\omega_o}\left[\frac{V . E_f}{Z_c} . \sin(\delta + \alpha_c) - R_c . (E_f / Z_c)^2\right] = f(V , E_f , \delta) \qquad (2-1)$$

T_{as} := Electric Developed asynchronous torque of all electrical damping circuits of the rotor.

$$= \frac{3 \cdot P}{\omega_o} \cdot \frac{E_\xi^2}{R_{damp}} (1 - \omega_\pi) = f(E_\xi, \omega_\pi) \qquad (2\text{-}2)$$

T_{db} := Damping torque due to friction and windage losses.

$$= \frac{1}{2\pi N_s} \cdot \left[(MWN - MWL) \cdot 10^6 - 3 \cdot I_c^2 \cdot R_c \right] \cdot \omega_\pi = f(MWN, I_c, \omega_\pi) \qquad (2\text{-}3)$$

The third equation gives the rotor position measured of the rigid inverter impulse, as seer in the vector diagram given in Fig.(3),

where ;

$$\xi = \beta + \delta \qquad (3\text{-}1)$$

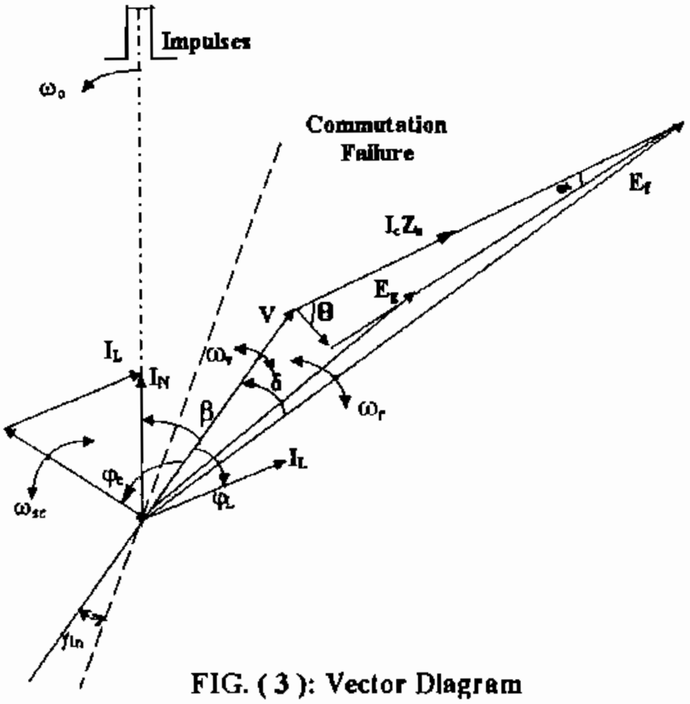


FIG. (3): Vector Diagram

3.4. Initial Conditions :

The initial conditions required to solve the above differential equations must be determined from a time interval to the other accordings to the control type. For each type, the controlled variables are declared as constants. The other variables are determined as follows :

(a) Control Type (1) :

Here ; V_{DI} , V , and β are constant . Then :

- $\delta = \xi - \varphi_N$,

where:

$\varphi_N \equiv \beta$, and

ξ is the solution of the previous interval.

- The AC inverter current :

$$I_N = \frac{V}{C1 + C3 \, . \tan\delta} \, . \left[\frac{C2}{Z_L} + \left(\frac{C4}{Z_L} + 1 \right) . \tan\delta \right]$$

where :

$$\begin{bmatrix} C1 \\ C2 \\ C3 \\ C4 \end{bmatrix} = \begin{bmatrix} \sin\phi_N & \cos\phi_N \\ -\sin\phi_L & \cos\phi_L \\ \cos\phi_N & -\sin\phi_N \\ \cos\phi_L & \sin\phi_L \end{bmatrix} . \begin{bmatrix} R_c \\ X_{sc} \end{bmatrix}$$

- The inverter commutation angle

$$\gamma_N = \sin^{-1} \left[\sqrt{1 - (2\,C5)^2} \, . \cos(180 - \beta_o) - 2.C5.\sin(180 - \beta_o) \right]$$

where :

$C5 = 0.5 \, . \cos(180 - \beta_o) - \sin\gamma_o/2$ and

γ_o:= value of commutation angle of the converter acting as uncontrolled rectifier. Its value is taken from 20° to 30° according to loading ratio.

- $I_D = I_N \,/\, [(\sqrt{6} \,/\, \pi) \, . \cos(\gamma_N / 2)]$
- $V_{DR} = V_{DI} + I_D.R_d + L_d.(I_D - I_{DD}) \,/\, \Delta t$

  where :

  I_{DD} is the previous value of I_D .

(b) Control Type (2) :

Here, V_{DR} and V are constant. Then :

- The compensator torque angle δ can be determined from the equation:

  $a \, . \sin^2\delta + b \, . \sin\delta + c = 0$

  where :

  $a = C6^2 + C7^2$

  $b = -2.C7.(\sqrt{6}/\pi)[X_{sc} \, . \cos(\xi) + R_c \, . \sin(\xi)]$

  $c = [(\sqrt{6}/\pi) \, . I_D \, . (X_{sc} \, . \cos(\xi) + R_c \, . \sin(\xi))]^2 - C6^2$

  $C6 = I_L R_C \, . \sin\phi_L - I_L R_C \, . \cos\phi_L$

  $C7 = V + I_L X_{sc} \, . \sin\phi_L + I_L R_C \, . \cos\phi_L$
- $\phi_N = \xi - \delta$
- $\gamma_N = 2. \sin^{-1}(I_D X'_{sc} / (\sqrt{6} \, . V \, . \sin\phi_N))$
- $\beta = \phi_N + (\gamma_N / 2)$
- $I_N = (\sqrt{6}/\pi) \, . I_D \, . \cos(\gamma_N / 2)$
- $V_{DI} = 3 \, . (\sqrt{6} / \pi) . V \, . \cos\phi_N \, . \cos(\gamma_N / 2)$

(c) Control Type (3) :

Here, V_{DR} and E_f are constant. Then :

$$\phi_N = \tan^{-1}\left[\frac{\sin\xi - (C12 + C13 . C9 / C8) . I_D - C14 . \cos\xi}{\cos\xi + (C11 - C13 . C10 / C8) . I_D + C14 . \sin\xi}\right]$$

where :

$C8 = 1 + (R_C / Z_L) . \cos\phi_L + (X_{sc} / Z_L) . \sin\phi_L$

$C9 = (\sqrt{6} / \pi) . R_C$

$C10 = (\sqrt{6} / \pi) . X_{sc}$

$C11 = (\sqrt{6} / \pi) . R_C / E_f$

$C12 = (\sqrt{6} / \pi) . X_{sc} / E_f$

$C13 = (R_C / Z_L) . (\sin\phi_L) / E_f$

$C14 = Ef . C13 / C8$

- $\delta = \xi - \phi_N$
- $V = (E_f / C8) . \cos\delta + (C9 / C8) . I_D . \cos\phi_N - (C10 / C8) . I_D . \sin\phi_N$
- $\gamma_N = 2 . \sin^{-1}\left[I_D . \frac{X'_{sc}}{\sqrt{6} . V . \sin\phi_N}\right]$
- $V_{DI} = 3 . (\sqrt{6} / \pi) . V . \cos\phi_N . \cos(\gamma_N / 2)$
- $\beta = \phi_N + (\gamma_N / 2)$
- $I_N = (\sqrt{6} / \pi) . I_D . \cos(\gamma_N / 2)$

Now, the rest of variables, irrespective of the control type, can be determined as follows :

- $\phi_C = \tan^{-1}\left[\frac{I_N . \sin\phi_N + I_L . \sin\phi_L}{I_N . \cos\phi_N - I_L . \cos\phi_L}\right]$
- $I_C = I_N . (\sin\phi_N / \sin\phi_C) + I_L . (\sin\phi_L / \sin\phi_C)$
- $MWN = 3 . V . I_N . \cos\phi_N . 10^{-6}$
- $I_{Bs_1} = [(MWR - MWN) . 10^6 - I_D^2 . R_d] / V_D$

For control type (1) , $V_D = V_{DI}$
For control type (2) & (3) , $V_D = V_{DR}$
For control type (1) and (2) :

$$E_f = \frac{V + I_C . Z_{sc} . \cos(\phi_C + \vartheta - 180^\circ)}{\cos\delta}$$

- $\gamma_C = \tan^{-1}\left[\frac{E_f . \sin\delta - I_C . (X_{sc} - X_{pc}) . \sin(\phi_C - 90)}{E_f . \cos\delta - I_C . (X_{sc} - X_{pc}) . \cos(\phi_C - 90)}\right]$
- $E_s = \left[\frac{E_f . \cos\delta_C - I_C . (X_{sc} - X_{pc}) . \cos(\phi_C - 90^\circ)}{\cos\gamma_C}\right]$
- $\omega_r = 1.0 + (\phi'_N - \phi_N) / \Delta t / \omega_o$
- $\omega_{sc} = 1.0 + [(\phi_C - \phi_N) - (\phi'_C - \phi'_N)] / \Delta t / \omega_o$

4. DIGITAL FORMULATION :

The developed mathematical model had been programmed for computer ; using the MATLAB software. The main outlines of the programming is illustrated in the flow-chart given in Fig.(4). The calculations can be directed to get the dynamic behaviour of the system during synchronization or load variation ; applying a given type of the suggested controls. The non-linearity of the basic equations impose the initialization of whole direct and indirect variables ; interval by interval.

All system failures, which may be probably happen, can be detected at once by testing the values of some pre-chosen operation variables. Any detected failure will be signalized and the program stops. Examples for such failure are :

(a) "Compensator Excitation Exceeds Its Limit" ; that means the compensator field is subjected to heat stresses.

(b) "Beta Less Than Commutation Angle" ;that means the system has inversion failure.

(c) "Beta Exceeds The Upper Limit, (60 Degrees)". Here, the reactive power increases. Also, the system will operate under highly distorted wave-forms due to the increasing content of higher-harmonics.

In cases, in which the system approaches steady-state normally without failures, the calculations is left running for a short time before the program stops.

5. RESULTS AND DISCUSSIONS :

Figures (5) to (10) show the dynamic behaviour of the suggested system assuming a rated load of 5 KVA. The specifications of the rest of the setup is taken in accordance with the assumed load power. This behaviour is calculated either during synchronization or load variation at different power factors. For either of both cases and assuming a given control-type, the calculations are carried out taken into consideration the effect of the compensator damper and DC-link parameters (R_{damp} , L_d and R_d), as well as the effect of some operation variables such as β and ω_{rr}.

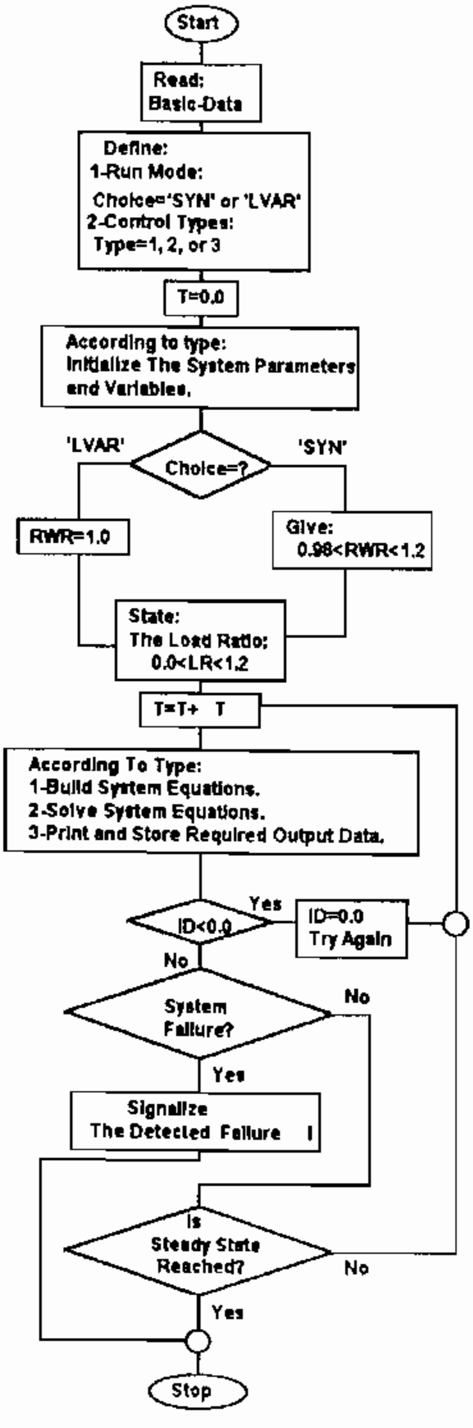


Fig. (4) : Flow Chart

Summarized , the figures reveal that :

1- The DC-link inductance L_d must be properly chosen. As small values reduce system oscillations, large values are required to suppress the DC-link ripples, Fig. (5-1a).

2- The DC-link resistance R_d has a little help for stabilizing the system oscillations. It should be small as possible to reduce the DC-link copper losses , Fig. (5-1b).

3- The damping effect of the compensator – damper is inversely proportional to the value of the damping resistance, R_{damp}. Therefore, the damper-winding must be properly designed tensure thet the system will not go out of stability ; especially in case of control types (2) and (3) , Fig. (5-2a).

4- Successful synchronization will be attained if the slip between the frequency of rigid impulses and the frequency of the voltage applied to the inverter terminals is too small; within 0.001 , Fig. (5-2b). Also, the processing of synchronization under a proper initial β will add to the system stability, Fig. (5-2c). Open-circuited load while synchronizing must be avoided, Fig. (5-2d).

5- Sudden large decrease of load or load opening may force the system to go out of stability ; especially in case of control types (2) and (3), Fig.(7). In the other side , sudden large increase within the full-load will maintain the system stability ; Fig. (6).

6- It is necessary to control the voltages on both sides of the inverter , by controlling the rectifier and the compensator excitation. Thereby the advance angle of the inverter can held constant at a reasonable value in order to minimizel its reactive power demand, Figs. (5) to (10).

According to the above discussions, control type (1) has approved it self to be the best strategy may be applied to the suggested system.

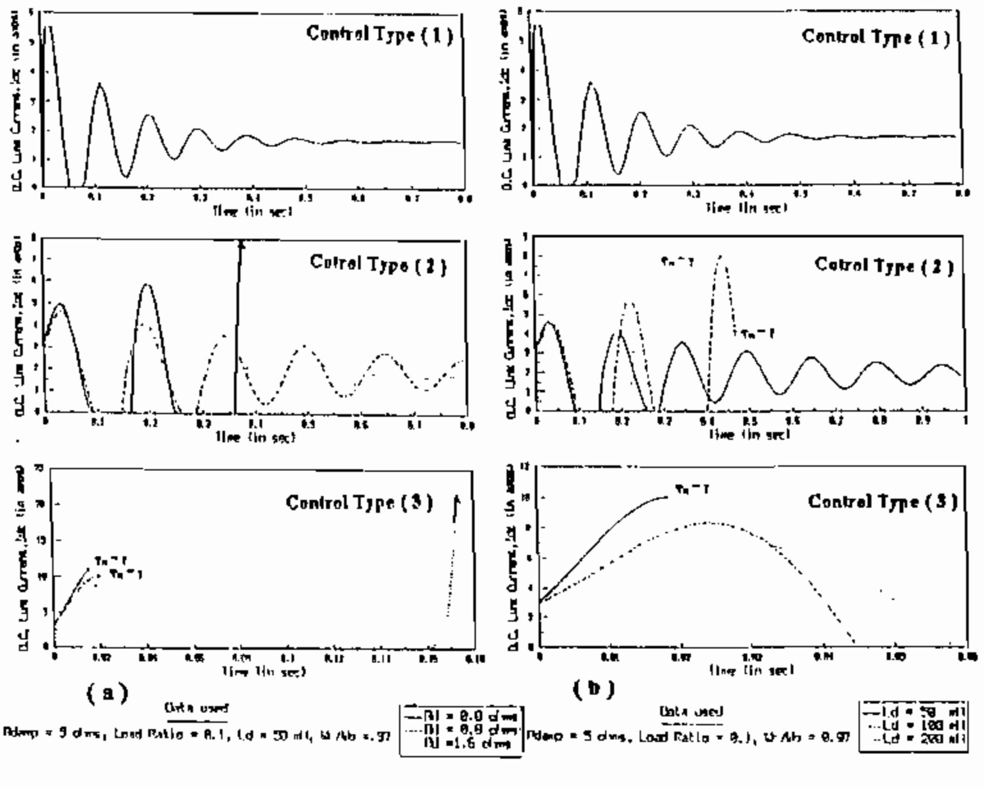


Fig. (5 - 1) : Dynamic behaviour after closing S.SW under light load , rated power factor :
(a) Different DC-Link resistance. (b) Different DC-Link reactance.

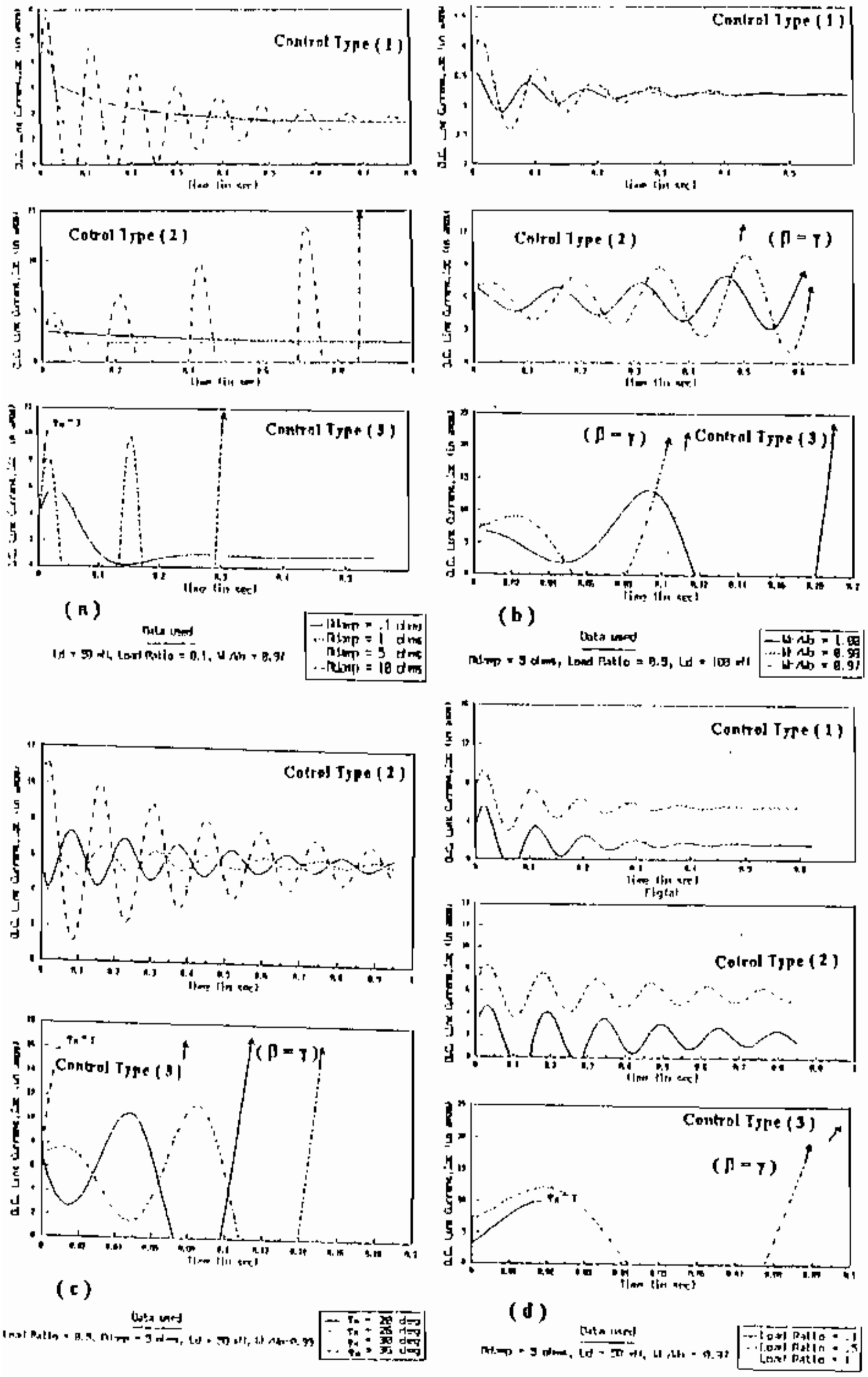
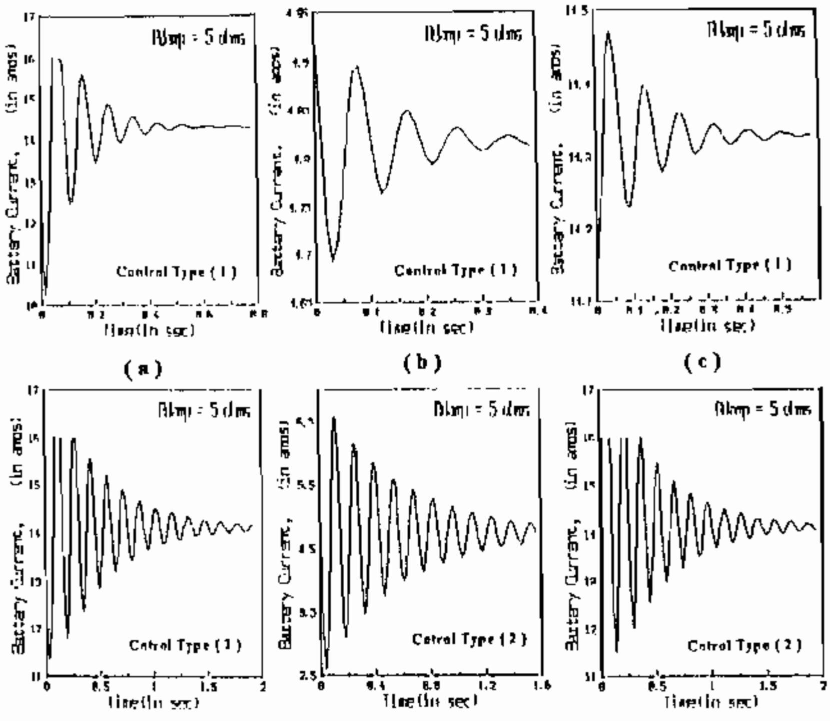


Fig. (5 - 2) : Dynamic behaviour after closing S.SW. under light load , rated power factor :
(a) Different damping effects. (b) Different relative rotor speeds.
(c) Different Inverter P.F. (d) Different load ratios.



Data used Ld = 50 mH, Wr/Wb = 0.97

Fig (8) : Battary current in control type (1) and (2) at :
(a) Synchronization. (b) Increasing load. (c) Decreasing load.

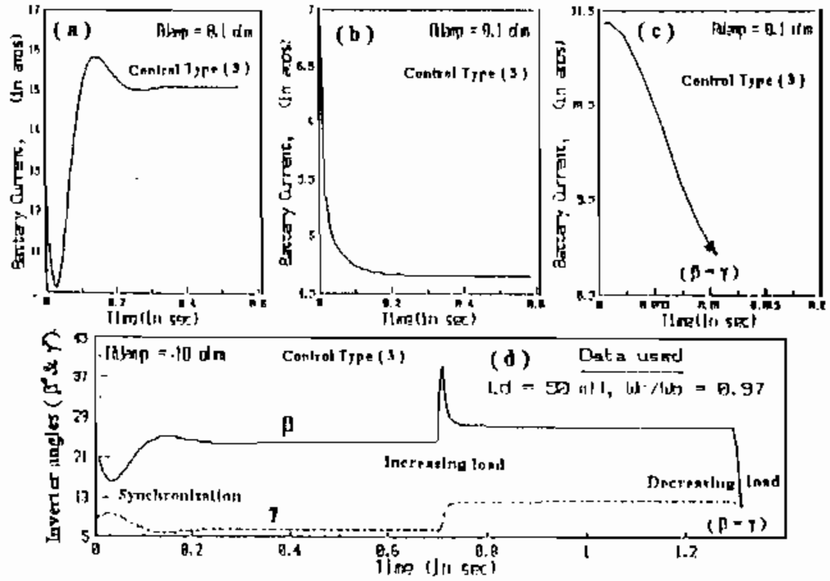


Fig (9) : Synchronization and load variation in control type (3) :
(a) Battary current at synchronization. (b) Battary current at increasing load.
(c) Battary current at decreasing load. (d) Inverter angles (β & γ).

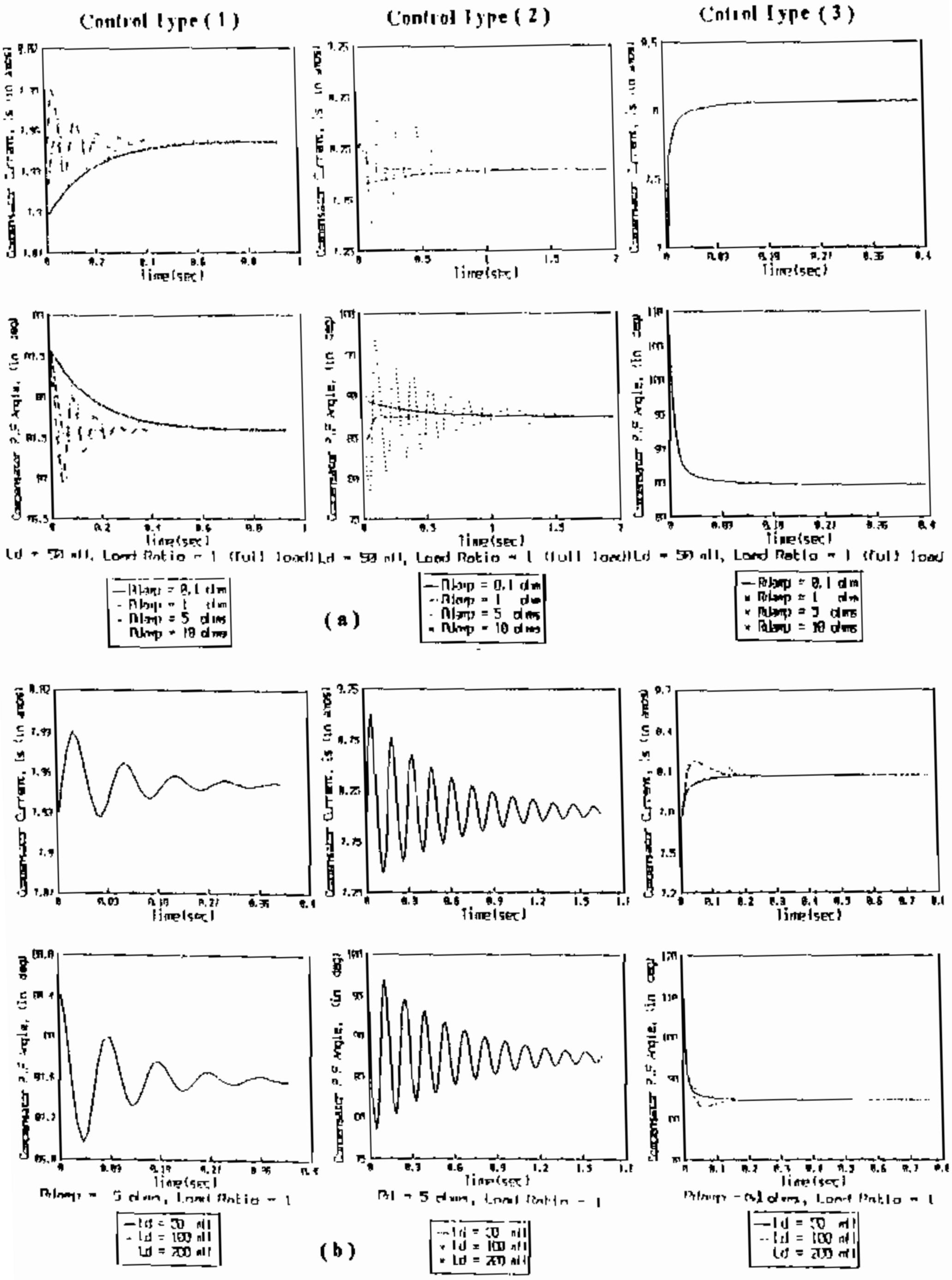


Fig (6) : Dynamic behaviour due to sudden application of rated load at rated power factor :
(a) Different damping effects. (b) Different DC-Link reactances.

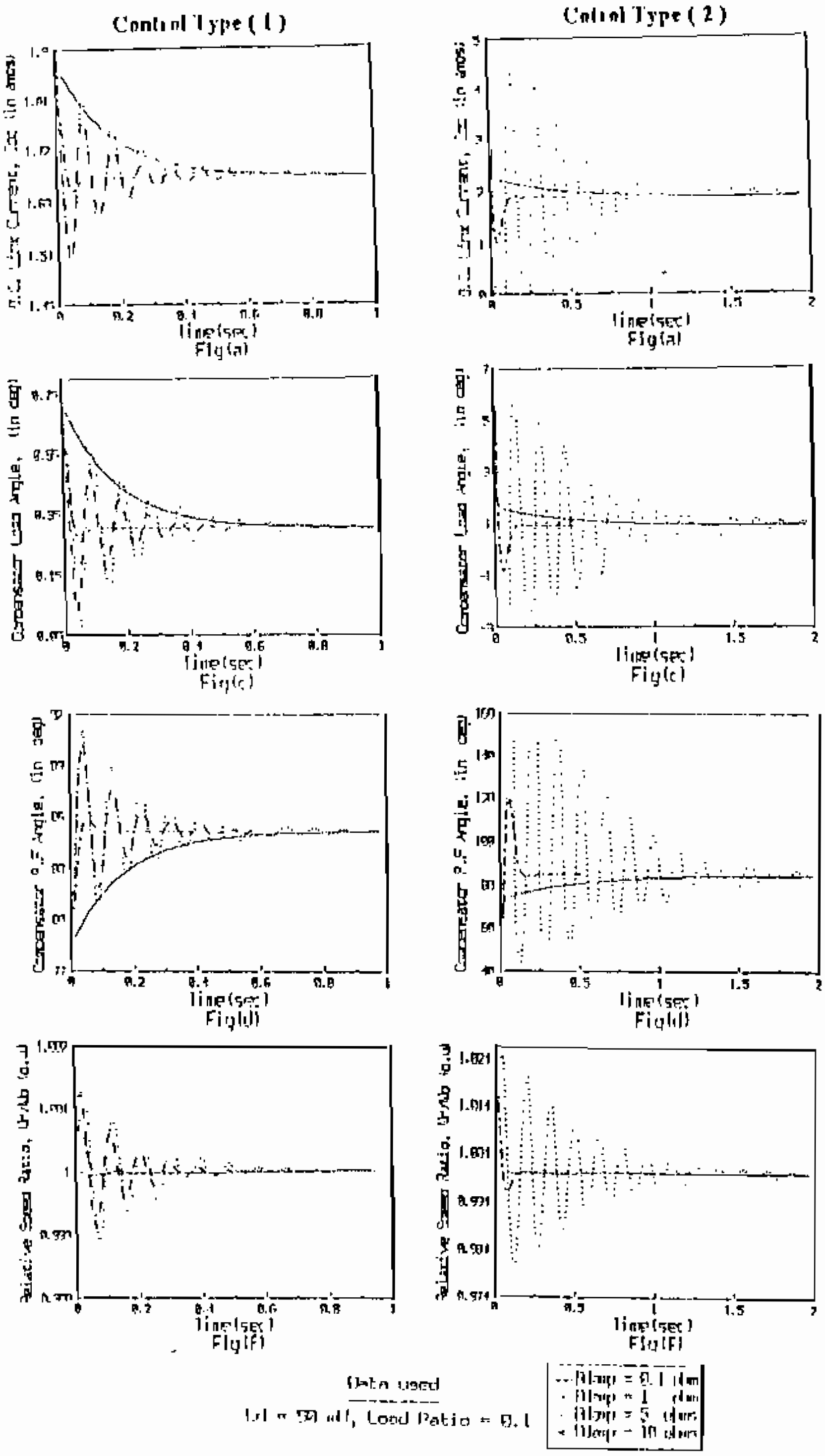


Fig (7) : Dynamic behaviour due to sudden reduction of load to light load at rated P.F.

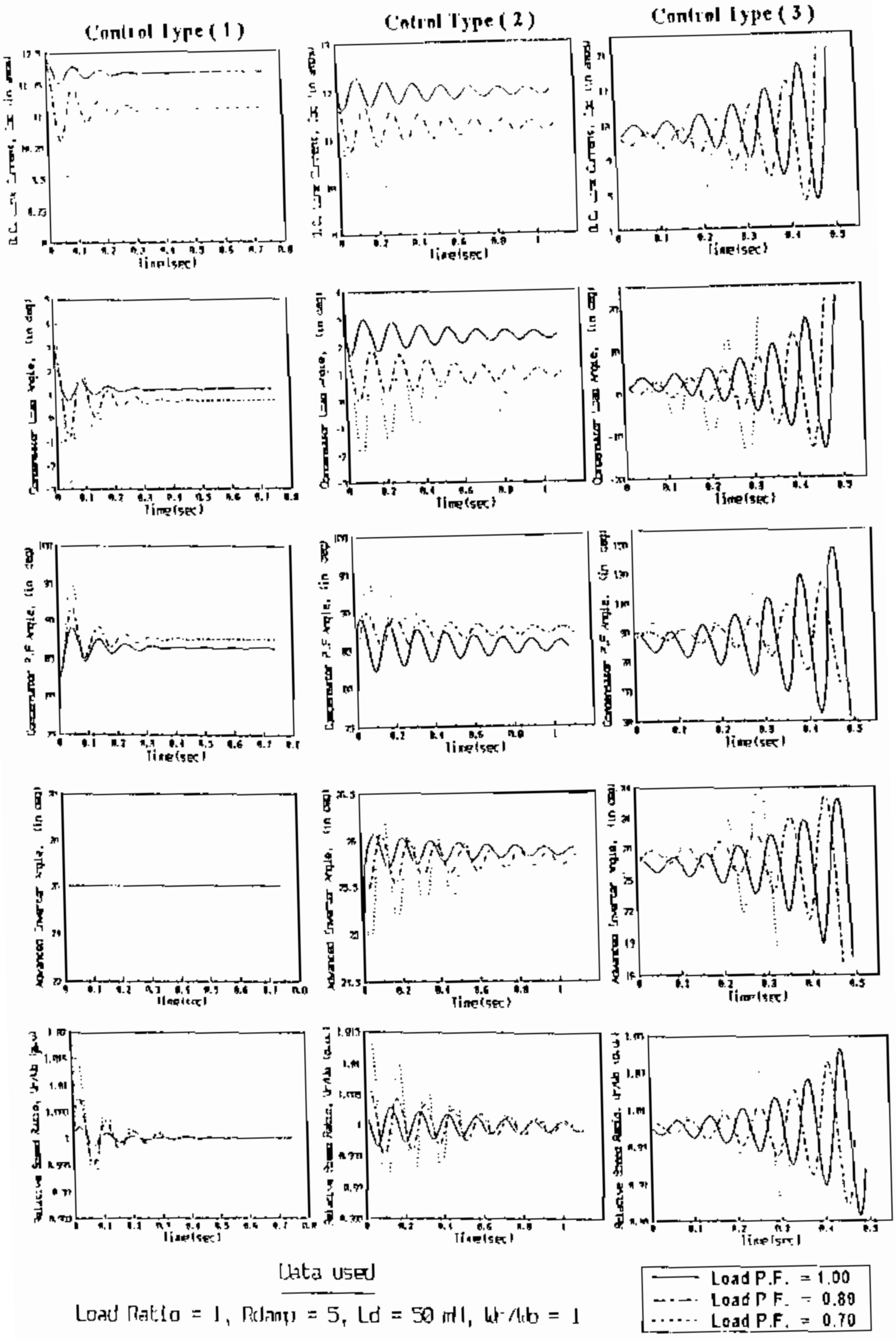


Fig (10) :Dynamic behaviour due to sudden application of rated load ; three different load P.Fs.

6. CONCLUSIONS :

The mathematical simulation of the load side dynamic behaviour of a wind energy/ isolated load system has been successfully developed, in spite of the non-homogeneity of this system. The corresponding mathematical algorithm is programmed ; using the software MATLAB. The written program is able to examine the dynamic behaviour of the mentioned system during synchronization and sudden load variations. The effects of some pre-chosen parameters and operation variables on this behaviour can be considered.

The results reveal that the system synchronization can be successfully processed if the following conditions are fulfilled :

(1) The frequency of the synchronous machine generated voltage applied to the inverter terminals is too closed to the frequency of the rigid frequency of the inverter impulses.

2) The initial value of the advance angle must be precisely determined to ensure good match between the voltages across both sides of the inverter.

3) The start with quite enough load to ensure continuous ignition of the inverter thyristor unites.

Either during synchronization or load variation the parameters of the DC-link and the compensator damper-winding must be properly chosen. Thereby, system oscillations can be suppressed.

The results reveal also that a control strategy, which depends on the continuous control of the voltages across both inverter sides to hold them constant, will be suitable. This-way, the advance angle β and, in turn, the reactive power demand of the inverter can be minimized. In accordance with dynamic behaviour due to sudden load variation, increasing the load with reasonable increment does not lead to any abnormal behaviour. In opposite to this result, sudden load decrease will give probably arise to system failures.

Therefore, it is recommended to protect the system against sudden opening of load. It is recommended, also, that the load power factor must be within unity and its rated value. The operation with load power factors less than rated provides a reason for instability due to the increasing demand of reactive power.

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NOMENCLATURE :

E	Compensator induced voltage , volt.
I	AC or DC current , Ampere.
J	Polar moment of inertia , kg-m^2.
R	AC or DC resistance , Ohm.
T	Developed torque , kg.m .
Δt	Time interval , second.
V	AC or DC voltages , volts.
ω	Rotating fields speed , rad./sec.
N	Rotating Shaft speed , r.p.m.
p	Number of pole pairs of synchronous compensator.
X	Synchronous compensator reactance , Ohm.
Z	Synchronous compensator impedance , Ohm.
α&θ	Synchronous compensator impedance angles , degrees.
ϕ	Power factor Angle , degrees.
δ	Torque angle , degrees.
γ	Inverter commutation angle , degrees.
β	Inverter advance angle , degrees.

SUBSCRIPTS:

as	Denotes asynchronous value.
Bat	Denotes the Battary bank.
c	Denotes the compensator.
d & D	Denote the DC-link parameters and variables.
DR or DI	Denotes the DC voltage behind the smoothing reactor or the inverter bridge ; respectively.
damp	Denotes the compensator damping circuits.
db	Denotes the torque due to friction and windage losses.
f & g	Denote excitation and air-gap ; respectively.
L	Denotes the applied load.
s & sc	Denote synchronous & synchronous compensator ;respectively.
rr	Denotes rotor relative value.
pc	Denotes synchronous compensator Potier reactance.

SUPERSCRIPTS:

.	d/dt
'	Denotes a previous or transient value.

ABBREVIATIONS:

MWL	Power of applied load in Mega-Watts.
MWN	Power output of inverter in Mega-Watts.
MWR	Power output of rectifier in Mega-Watts.